Douglas Sky Train (*Skymaster*); Army C-54 Combat Transport

(*Frontispiece.*)

AIRCRAFT MECHANICAL DRAWING

BY

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AND

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Santa Monica, California

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AIRCRAFT MECHANICAL DRAWING

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To the engineers and draftsmen all of whom have contributed their share to the progress and development of the science of engineering drawing

PREFACE

This course has been designed for the student who has had no previous instruction in mechanical drawing or whose skill and understanding of this subject have declined from disuse. Prerequisites are arithmetic and elementary algebra; in addition, geometry, trigonometry, and an acquaintance with manufacturing processes will be found helpful. The knowledge of mechanical drawing gained from this course will serve as a background, enabling the student to study detail drafting and thus qualifying him for a productive position in an aircraft engineering department.

Use of drawing equipment, lettering, application of geometry to drawing, orthographic projection, standard aircraft and mechanical drawing practices, nomenclature, and typical aircraft and mechanical detail parts are the principal subjects of instruction. The materials used, the problems assigned, and the method of presentation conform as nearly as possible to the work encountered daily by those engaged in the preparation of productive engineering drawings. No attempt is made to cover the entire theoretical field of orthographic projection and of plane and descriptive geometry. The subject matter is confined to the essential principles and skills required for a thorough knowledge of practical drafting.

The subject matter is presented by means of discussions, explanatory exercises, and applied drawing problems, which latter develop manual skill and comprehension of the fundamentals of drafting simultaneously. It is intended that study should be supervised by the instructor and, from time to time, supplemented by demonstrations of difficult points and by discussions of related general subjects to familiarize the student with the work done in engineering departments and with the basic principles of mechanical design and construction.

The material that comprises this text has been drawn from a wide range of sources. The authors extend their thanks and deep appreciation to Mr. Brantley DeLapp, who first organized

and taught the course in aircraft mechanical drafting under the auspices of the Douglas Aircraft Company and the Santa Monica Technical School. The basic arrangement and a large part of the problem material of the text have been drawn from the foundation laid by Mr. DeLapp, and his kind help and suggestions to the authors have been invaluable. It seems fitting here to acknowledge the work of Mr. Raymond Sholes and Mr. Frank Fleming, who pioneered courses in drafting prepared and conducted by engineers actively engaged in productive work. Their experience has contributed in no small measure to the preparation and the manner of presentation of this text. Mr. Norman Meadowcroft and Mr. Newton H. Anderson, who have previously prepared advanced texts—to which this one is but an introduction—have been very kind in their assistance and guidance. The program of upgrading Douglas engineering and shop employees to positions of draftsmen and layout men by means of courses prepared and taught by engineers was conceived by Mr. C. T. Reid; and through his persistent work and sponsorship over a period of five years these courses have been developed and now are published in book form. A particular expression of gratitude is extended to Mr. Edward Radebaugh, who has supervised the preparation of the illustrations, and to Miss Mona Seppi, who has meticulously typed the drafts of the text. The persons whose contributions have been acknowledged above are all employees of the Douglas Aircraft Company. The authors are indebted to the Douglas Aircraft Company for its permission to use illustrations and material from the Engineering Drafting Manual and Design Manual and to the Keuffel & Esser Company of New York and the Charles Bruning Company for illustrations of drafting instruments.

D. J. Davis,
C. H. Goen.

Santa Monica, Calif.,
November, 1944.

CONTENTS

FOREWORD

Even before Pearl Harbor there developed in the expansion of the aircraft industry a scarcity of qualified applicants for drafting work. Applicants with the highest qualifications disappeared first. As time went on it became difficult to find applicants with even mediocre qualifications, and finally the applicants had no drafting training at all.

As each level of skill vanished from among available applicants, it became necessary to start a training course to develop that skill. The Douglas Aircraft Company faced this situation and provided full-time training in the engineering department for qualified employees. First, only layout and design men were trained; then, training of detailers had to be started. Finally, when it became evident that men would have to be trained "from scratch," the assistance of the public schools was sought. The Santa Monica Technical School generously made available its facilities.

In order to offer effective training it was agreed that the company would furnish teaching talent capable of creating text material that would apply principles of mechanical drawing directly to aircraft problems. Two young engineers, David J. Davis and Chester H. Goen, were prevailed upon to undertake the task. In the company's earlier experience of training at higher levels, text material prepared from actual work examples had produced two very successful books: *Aircraft Layout and Detail Design*, by Newton H. Anderson, and *Aircraft Detail Drafting*, by Norman Meadowcroft. Anderson and Meadowcroft wrote their separate study courses for the higher and the intermediate levels of aircraft drafting, because no suitable text was in existence. Now Davis and Goen have collaborated to furnish a textbook at the elementary level. This study course is intended as the foundation of the series, the basis upon which the rest of the training will henceforth be built for complete, well-rounded development in drafting as applied to the manufacture of aircraft.

The McGraw-Hill Book Company experienced heavy demand for Anderson's and Meadowcroft's books and urged us to add more to the series. Our understanding with them was, from the outset, that the two books covered but the upper two-thirds of a single training program. They have joined us in eager anticipation of the time when the elementary third book should join the set. In keeping with the high quality that characterizes their publications, they have patiently waited until the course could be perfected through several cycles of use.

Divisions of the topic have been made, changed, and changed again, to profit by the experiences of teachers and students. Illustrations and examples have been tried, discarded, and others tried in their places until items were found to "ring the bell." Explanations have been written, revised, and boiled down into the simple, objective language of the practical man. Theory is clinched in the learner's mind by application to real problems selected from the industrial job.

The present volume well deserves its place among industrial texts that help prepare men and women to do the kind of work that has to be done in the manner in which industry wants its work done.

C. T. Reid,
Man Power Assistant to
Vice President—Engineering,
Douglas Aircraft Company, Inc.

AIRCRAFT MECHANICAL DRAWING

CHAPTER I

INTRODUCTION TO MECHANICAL DRAWING

1.1. Historical Development.—Drawing is an outgrowth of man's desire to represent objects and events. It dates back to prehistoric times when cave men drew crude pictures on the walls of their dwellings, sometimes recording historical events. These picture stories were the forerunners of written language; pictures came to represent words and then, by simplification to a few curved and straight lines, became letters. Architecture, drawing, painting, and sculpture developed to a high artistic level in very early times. In order to design the monumental buildings of antiquity, the ancient craftsmen must certainly have made drawings or sketches to crystallize their ideas of the form and the design they were to create, but there was no extended use of what may be considered mechanical drawing until the design of machinery necessitated it.

Sketches or paintings show the form of an object but do not give its exact size. The reason for this is that drawing and painting are based on perspective drawing, in which the object is viewed from an angle, and the portions of the object closer to the eye are represented larger than equal portions that are farther away. A photograph of a row of telegraph poles shows the nearer ones higher than the more distant ones, although they actually are all the same height. This type of drawing makes an object look natural and gives it depth when it is represented on a flat surface, but dimensions may not be scaled from such a picture.

Figure 1.1 shows a sketch of a block 1 in. square and 3 in. long, as represented by perspective drawing. This looks like a block

but shows the near square end much larger than the far square end.

Orthographic projection meets the need for an accurate picture of an object. Figure 1.2 shows the same block represented by orthographic projection. It is a diagram of the block rather than a visual representation of the object and it may be defined as the shadow that an object inside a glass box would cast upon the top, front, and side of the box. It is as though the observer stood above the object and looked down upon it for the top view, stood at the front for the front view, and at the side for the side view. It should be noted that one view gives only two dimensions; for example, the side view gives the thickness and width of the part. At least a second view is required to give the third dimension, or length. It is necessary therefore to examine the top view or side view to find the length of the block.

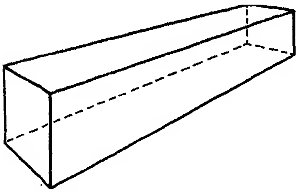


FIG. 1.1.—Perspective view of a block.

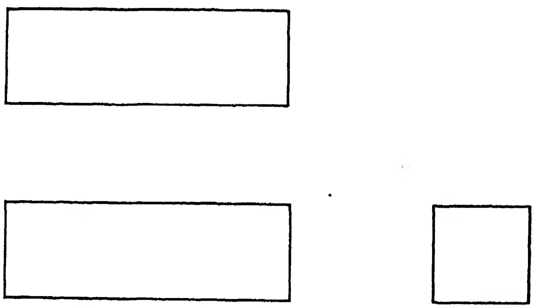


FIG. 1.2.—Orthographic views of a block.

A more detailed explanation of orthographic projection will follow in a later chapter. It is sufficient to say here that this type of drawing provides an accurate method of showing the exact size and shape of a part.

1.2. Objectives of Good Drawing.—Orthographic projection is the universal language used by designers to transmit their ideas to builders. Certain variations exist in the terminology used by designers in such fields as architecture and marine, structural, automotive, and aircraft engineering, but anyone familiar

with the basic principles of orthographic projection can soon familiarize himself with the peculiarities of different applications of this type of drawing.

Since a drawing is the guide by which a mechanic builds a physical part, it is necessary that a drawing be absolutely clear, free from errors, and not subject to any possible misinterpretation. This is the personal responsibility of the draftsman, regardless of how many other people may be assigned to check his work. The responsibility for any error falls directly upon the draftsman preparing the drawing and errors reflect seriously upon his ability and usefulness, for they may cause the fabrication of many useless parts with the attendant waste of material, machine time, and man power. Speed next to accuracy is important, for a draftsman's value depends upon the amount of accurate work he can produce. Speed, however, is useless without accuracy. A slow draftsman who does not make mistakes is more valuable than one who draws rapidly but makes errors.

DRAWING INSTRUMENTS AND THEIR USE

1.3. Use of Drawing Paper.—Drawings are made on paper or on drawing cloth in pencil or drawing ink. In aircraft work the general practice is to use drawing paper and pencil. These pencil drawings are later traced in ink on drawing cloth to form a more durable record. Since the bulk of the work in an engineering department consists of the preparation of pencil drawings, the use of inking instruments will not be discussed in this text. Their use is a manual skill that can be acquired in a short time if necessary.

The drawing board should be covered with a piece of heavy detail paper before applying the regular drawing paper in order to prevent heavy pencil lines from marring it. By replacing the heavy paper as it becomes marred from use, a smooth drawing surface will always be provided. Next, the drawing paper should be fastened smoothly and securely to the drawing board. This may be accomplished by laying the paper rough side up, approximately square with the drawing board and as near the top as convenient. One corner should be fastened to the board with Scotch tape or a thumb tack, and the paper should be smoothed to the diagonally opposite corner and there fastened. The paper should then be smoothed from the center to one of the

remaining corners, fastened, and again smoothed to the last corner. If any wrinkles remain, they should be smoothed to a corner perpendicular to the line of the wrinkle and that corner should be fastened again.

1.4. Use and Care of Pencils.—Pencils of varying hardness should be provided for different types of lines. No set pencil hardness may be specified for any type of line because of variations in personal preference, in the surface roughness of the type of paper, and in the hardness of pencils of the same grade. In general, the hardest pencil that will produce the desired line should be used, since the softer grades of pencil smear the paper and the lines tend to fade out with age and handling.

Lines should be uniform in width and dense black, regardless of width, since the original paper drawings are seldom used to make actual airplane parts but are copied by the blueprint process for use in the shop. This process consists of placing the original drawing between a bright light and a piece of sensitized paper. The bright light shining through the blank spaces of the drawing affects the sensitized paper, while the pencil lines shut off the light from the paper. When the sensitized paper is developed into blueprints, those areas not affected by the light remain white, while the remainder or background turns blue, thus showing white lines on a blue background. If the lines on a drawing are not dense black, the light will penetrate them when the blueprints are made, thus producing a more or less blue line that blends into the blue background, making the print illegible. Figure 1.3 shows a blueprint of lines made with pencils of varying hardness, different degrees of sharpness, and traced over one, two, and three times. It may be seen that the same clarity can be obtained by using a harder pencil and by tracing over the line, as with a softer pencil, but without the undesirable smudging that the softer pencil produces. Also it should be noted that the sharp-pointed pencil produces a sharper, more uniform line than a dull pencil.

Pencil hardnesses range from F, or very soft, to 6H, or extremely hard. A medium-soft grade of pencil should be used for lettering and heavy lines; a medium-hard grade for lighter lines, such as dimension lines, center lines, etc.; and a hard grade for construction lines, guide lines, or any other lines necessary in making the drawing but not desired on the blueprint.

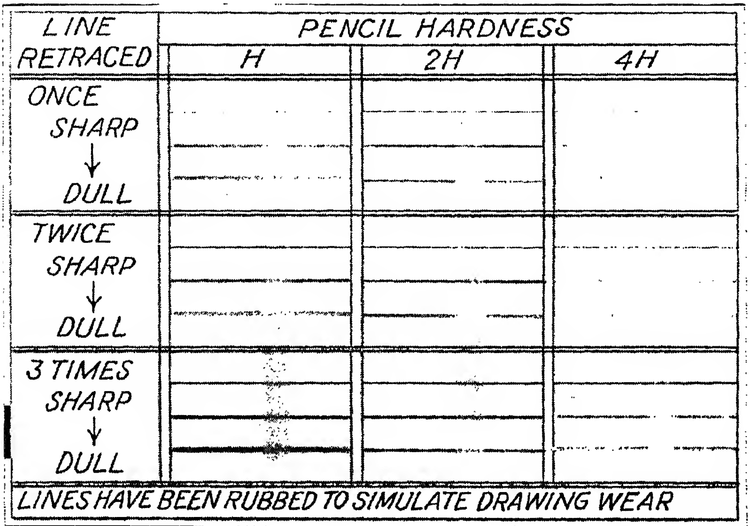


FIG. 1.3.—Blueprint of pencil lines.

(Facing page 4)

It is very important that pencils be properly sharpened and kept sharp. The wood should be cut away smoothly until about $\frac{3}{8}$ in. of lead projects beyond the wood. The blunt lead point is drawn back and forth across either a fine mill file or a block covered with fine sandpaper; at the same time the pencil should be rolled between the thumb and the forefinger until a long, conelike point is produced (see Fig. 1.4). Care should be taken that the point is neither flat nor lopsided.

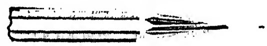


FIG. 1.4.—Conical pointed pencil.

Pencil lines are always drawn with the aid of a T square, triangle, straightedge, drafting machine, or irregular curve. The pencil should be tilted slightly in the direction in which the line is being

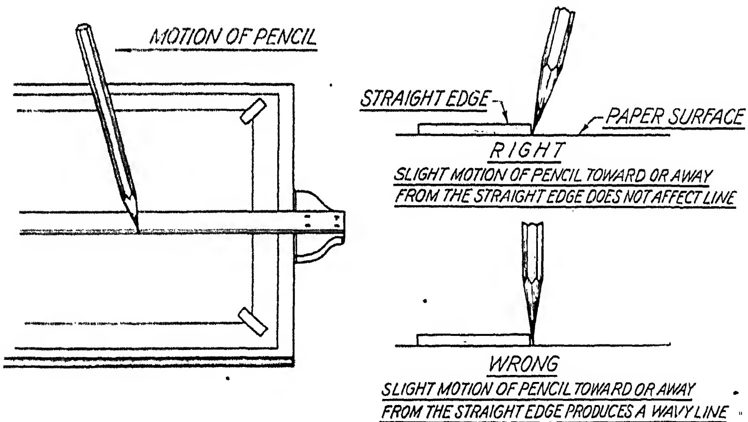


FIG. 1.5.—Position of pencil when drawing lines.

drawn and away from the straightedge (see Fig. 1.5). The pencil should be rotated slowly between the fingers as the line is drawn, thus preventing a flat spot on the pencil point, which would produce a fuzzy line.

Exercise

1.4.1. Draw several lines approximately 1 ft. long, being careful not to rotate the pencil. Examine the pencil point closely, and note the difference between the first and the last lines drawn. Resharpen the pencil and draw an equal number of lines of the same length, rotating the pencil as described above. Examine the pencil point closely, and notice the difference between the first and last lines. Which method of using the pencil will produce the

better lines? Refer to Fig. 1.3 for illustration of how these lines would blueprint.

The pencil should be frequently resharpened so that lines of uniform width and blackness may be obtained. Pencils should never be sharpened over the drawing or the drawing board, and stray particles of lead should be wiped from the pencil point before it is used on the drawing again. In no case should the mill file or the sandpaper block used for sharpening the pencil be placed either on the drawing or on the drawing board.

For drawing straight lines, the chisel-type pencil point is sometimes used in place of the conical point, particularly in design layout work where a very hard pencil is used. The wood is pared back from the lead as in preparing the conical point, but one side of the lead is rubbed against the file, producing the chisellike point shown in Fig. 1.6. When using this type of point, the flat or filed side is held against the straightedge. Care must be taken to prevent the pencil from rotating while drawing the line.

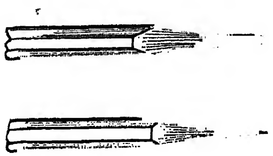


Fig. 1.6.—Chisel-pointed pencil.

To eliminate whittling, a mechanical drafting pencil is often used. It consists of a hollow metal tube, about the size of a wooden pencil, terminating in an adjustable jaw that is tightened to clamp the piece of lead contained within the tube. As the lead wears down, the jaws are loosened and the proper amount of lead is withdrawn and is resharpened.

1.5. Use and Care of the T Square.—The T square is used to draw horizontal lines. The short cross arm is held *firmly* against the left side of the drawing board while the line is drawn. When drawing a very long line, it is well to hold the long leg of the T square *firmly* against the drawing board. The T square should be used only against the left side of the drawing board and never against the top, bottom, or right side. If a good T square is used, as described above, and moved along the straight left side of a drawing board, lines drawn with the T square in different positions will always be parallel. Before using the T square, it is well to check that the short arm is firmly attached to the long arm, that the long arm is straight, and that the left-hand side of the drawing board is straight and smooth.

Exercise

1.5.1. Draw a series of 20 parallel lines, spaced   in. apart, using the T square as described above.

1.6. Use and Care of Triangles.—Triangles are used in conjunction with the T square for drawing lines that are not horizontal. The triangles are usually made of thin transparent material and may be obtained in various sizes. Two different

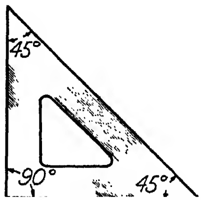


FIG. 1.7.—A 45-deg. triangle.

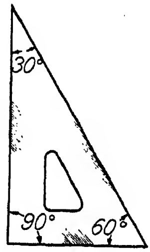


FIG. 1.8.—A 30–60-deg. triangle.

types of triangles are used: the 45-deg. triangle, one corner of which is a right angle and the other two corners are 45-deg. angles (see Fig. 1.7), and the 30–60-deg. triangle, one corner of which is a right angle, another corner a 30-deg. angle, and the third corner a 60-deg. angle (see Fig. 1.8).

Triangles are used to draw vertical lines by placing the T square as described in Sec. 1.5 and by holding one of the shorter legs of

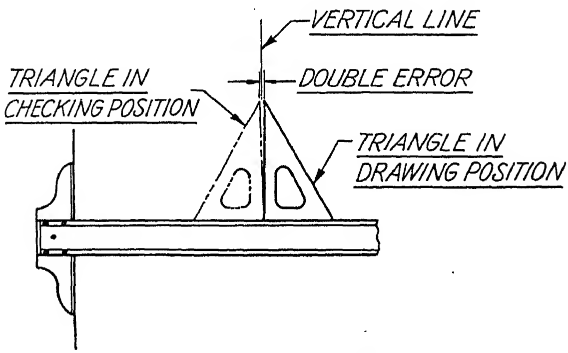


FIG. 1.9.—Checking a triangle.

the triangle firmly against the long leg of the T square. A triangle may be checked for squareness by drawing a vertical line from the left side of the triangle, then reversing the triangle so

that the vertical line is on the triangle's right side. When the triangle is held in the latter position against the T square, the line drawn in the former position will coincide exactly with the vertical edge of the triangle if the triangle is square (see Fig. 1.9). Two triangles may also be used to draw oblique parallel lines, *i.e.*, lines that are neither horizontal nor perpendicular, as shown in

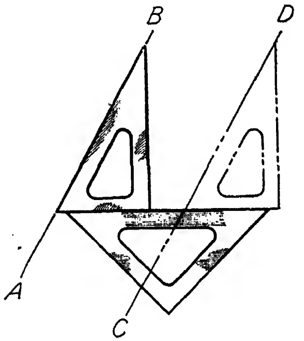


FIG. 1.10.—Drawing oblique parallel lines.

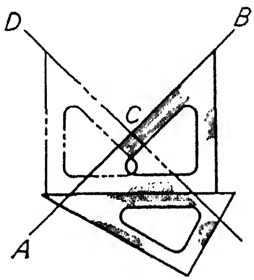


FIG. 1.11.—Drawing oblique perpendicular lines.

Fig. 1.10. One triangle is placed with its edge exactly on the given line *AB*. The second triangle is placed against the first and there held firmly while the first triangle is moved to the proper position for drawing the other parallel line, *CD*.

Exercise

1.6.1. Draw a horizontal line and mark off on it 10 points ½ in. apart. Through one of these points draw any line that is neither vertical nor horizontal and is approximately 4 in. long. Using two triangles, draw lines parallel to the first line through each of the remaining points.

By using the two triangles as shown in Fig. 1.11, a line may be drawn perpendicular to an oblique line through a point either on the oblique line or outside it. The hypotenuse of the 45-deg. triangle is placed on the oblique line *AB*, and the 30-60-deg. triangle is moved against one leg of the 45-deg. triangle and held there. The 45-deg. triangle is rotated so that the other perpendicular leg rests on the same side of the 30–60-deg. triangle, and the 45-deg. triangle is moved until the hypotenuse lies on the given point *C*; the required line *CD* is then drawn. The same procedure could have been used had the given point lain outside line *AB* as, for example, point *D*.

1.7. Use and Care of the Rule.—For measuring and laying out distances, a 12-in. rule divided into sixteenths or thirty-seconds of an inch is required, two types of which are illustrated in Fig. 1.12. The ability to measure distances from a drawing and to lay out distances on a drawing accurately and quickly is an essential skill of a good draftsman. Distances are most commonly measured and laid out in inches and common fractions of an inch to the nearest thirty-second, such as $1\frac{19}{32}$, $7\frac{1}{4}$, or $\frac{3}{16}$ in. Fractions involving sixty-fourths of an inch are seldom used.

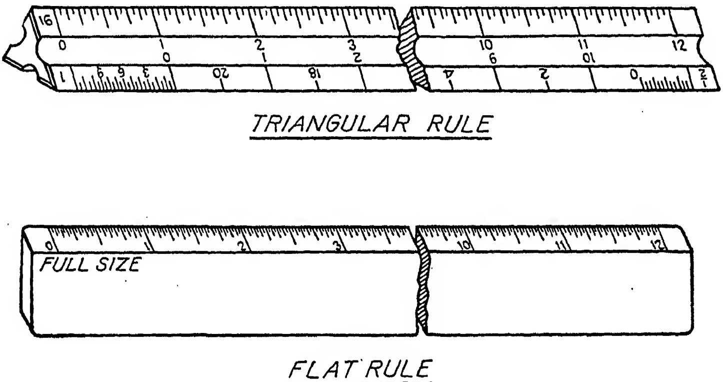


FIG. 1.12.—Types of rules.

Common fractions are always read and written in their simplest form, *i.e.*, $\frac{1}{2}$, not $\frac{16}{32}$ or $\frac{4}{8}$; $\frac{3}{4}$, not $\frac{12}{16}$ or $\frac{6}{8}$; $\frac{5}{8}$, not $\frac{20}{32}$ or $\frac{10}{16}$.

Referring to Fig. 1.12, it will be noted that the marks on the scale are of different lengths to facilitate the reading of dimensions. The marks denoting the inch points are the longest and are identified by the number of inches each represents. Midway between these numbered inch marks are the slightly shorter $\frac{1}{2}$-in. marks. Midway between the $\frac{1}{2}$-in. marks and the inch marks are the $\frac{1}{4}$-in. and $\frac{3}{4}$-in. marks, which are shorter than the $\frac{1}{2}$-in. marks. Between these marks are the still shorter $\frac{1}{8}$-in. marks denoting $\frac{1}{8}$, $\frac{3}{8}$, $\frac{5}{8}$, and $\frac{7}{8}$ in. On a scale divided into sixteenths, the shortest marks denote $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$, $\frac{7}{16}$, $\frac{9}{16}$, $\frac{11}{16}$, $\frac{13}{16}$, and $\frac{15}{16}$ in. A scale divided into thirty-seconds has still shorter lines for these smaller divisions representing $\frac{1}{32}$, $\frac{3}{32}$, $\frac{5}{32}$ in., etc.

In scaling or laying out a dimension such as $5\frac{9}{32}$ in., the first step is to locate the whole number of inches on the rule, and then to determine the location of the additional fraction. The practice of counting up the sixteenths or the thirty-seconds past the whole-number mark should be discouraged, since it is slow and subject to error. It is better to become thoroughly familiar with the more common fraction marks on the rule, such as the marks at $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$, $\frac{3}{4}$, and $\frac{7}{8}$ in. on the scale, so that one can call them out at a glance. If a dimension lies on a mark adjacent to these well-known marks, it is a simple task to determine whether the dimension is $\frac{1}{16}$ or $\frac{1}{32}$ in. greater or smaller than the better known fraction—provided the draftsman is familiar with the $\frac{1}{32}$ and $\frac{1}{16}$ divisions of the scale. Thus, a dimension terminating $\frac{1}{32}$ in. short of the $\frac{3}{8}$ mark would be determined as $\frac{3}{8}$ minus $\frac{1}{32}$, or $\frac{12}{32}$ minus $\frac{1}{32}$, or $\frac{11}{32}$ in. A dimension lying $\frac{1}{32}$ in. beyond the $\frac{3}{4}$ mark would be determined as $\frac{3}{4}$ plus $\frac{1}{32}$ or $\frac{24}{32}$ plus $\frac{1}{32}$, or $\frac{25}{32}$ in. Following this process, the draftsman will soon gain facility in transforming the more common fractions into their equivalents in sixteenths and thirty-seconds.

In using a scale divided into sixteenths, scaling and laying out measurements in thirty-seconds may be accomplished by estimating the mid-points between the $\frac{1}{16}$ marks as imaginary $\frac{1}{32}$ marks. Distances over 12 in. are most easily laid out or scaled by using a steel tape or a scale long enough to measure the entire distance. However, if a sufficiently long measuring device is not available, a light mark may be placed on the drawing to represent 12 in., the rule moved and another 12 in. laid off, and this process repeated until the end of the required distance lies within the length of the rule. The total length is then equal to the number of 12-in. spaces laid off plus the additional distance measured. The draftsman should train himself while using the rule to estimate distances by eye so that gross errors in dimensioning may be observed and corrected.

Dimensions that must be reproduced with less than $\frac{1}{32}$-in. deviation by the mechanic who makes the part are given in decimal fractions, such as .500 for $\frac{1}{2}$ in. or .688 for $\frac{11}{16}$ in. A table for converting common fractions to decimal fractions will be found in Chap. 6, where dimensioning is taken up in greater detail. All distances on a drawing should be laid out as accu-

rately as possible. The maximum error usually permitted in a drawing is $\frac{1}{32}$ in. However, distances that are more than $\frac{1}{64}$ in. out of scale are a sign of poor or careless drafting. In order to lay out distances with the least amount of error, the zero mark on the 12-in. rule should be placed exactly on the point from which the measurement is to begin, with the eye directly above that point. A mark should then be placed on the paper the desired distance away, with the eye now directly above the second desired point. It should be noted that the zero mark on the rule is located approximately $\frac{1}{4}$ in. from the end of the rule so that wear and injury to the end of the rule will not affect the zero mark and make the measurements inaccurate. In measuring the distance between parallel lines, care should be taken that the

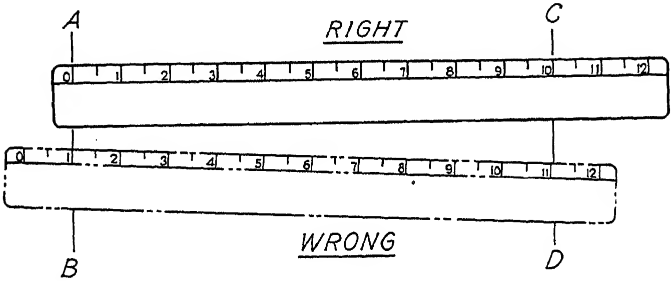


FIG. 1.13.—Measuring distances.

rule is placed perpendicular to the lines (see Fig. 1.13). Before too much detail work has been done on the drawing a careful check of distances should be made to discover errors when they may be easily corrected.

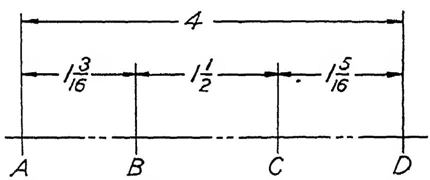


FIG. 1.14.—Measuring a series of points.

If a number of points lie in a straight line, not only the distance between adjacent points should be measured but also the distance from the first point to the last. Thus, in Fig. 1.14, the distance from A to B should be scaled to check the $1\frac{3}{16}$ in. dimension, the distance from B to C to check the $1\frac{1}{2}$ in. dimension, the dis-

tance from C to D to check the $1\frac{5}{16}$ in. dimension, and the distance from A to D to check that these points are 4 in. apart. When laying out a series of points such as those in Fig. 1.14, the best procedure is to place the zero mark of the 12-in. rule on the first point and leave it there, adding up the dimensions of the successive points. This procedure tends to eliminate the addition of errors which would accrue if the rule were moved for the measurement of each succeeding distance. The foot rule is never used to draw straight lines, since the indentations on the rule make the lines uneven. The 12-in. rule is used to measure the distances and a T square or straightedge to draw the lines.

Exercise

1.7.1. Measure the length of the lines in Fig. 1.15 to the nearest $\frac{1}{32}$ in. and note their combined length.

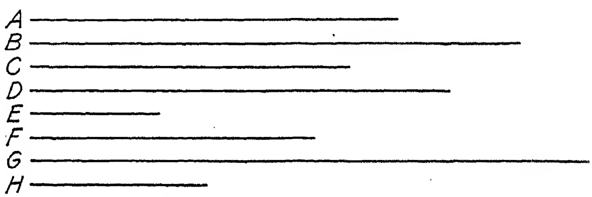
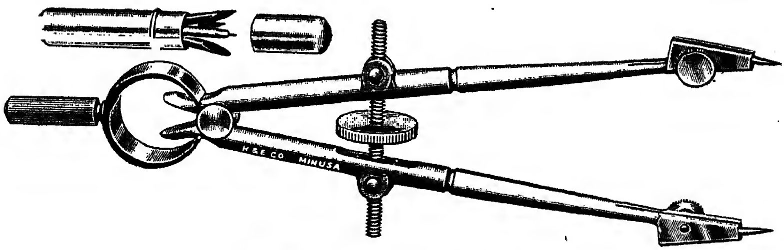


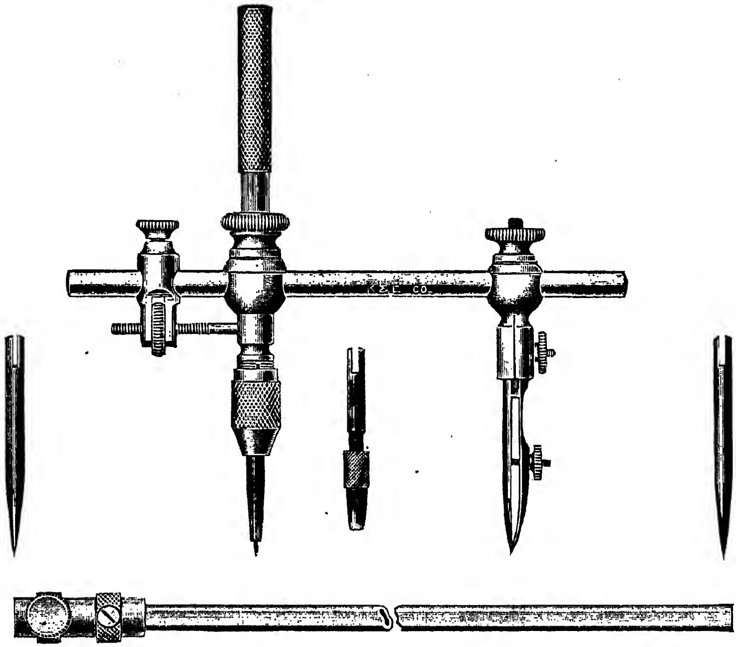
FIG. 1.15.—Measuring lines.

1.8. Use and Care of the Compasses.—Circles and arcs are drawn by means of a compass, several types of which may be used (see Fig. 1.16). The recommended combination is a large or 6-in. bow compass with a threaded adjustment for drawing circles up to 10 in. in diameter and a beam compass for drawing circles of greater diameter. A combination of a small or a 4-in. bow compass, a divider-type compass, and a beam compass will also serve. The first combination is recommended, since the bow-type compass is adjusted more easily and accurately than the divider-type compass.

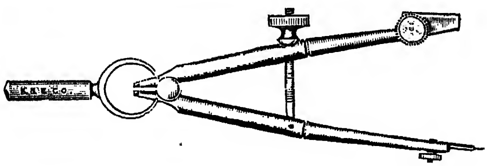
A circle is defined as a line, every point of which is the same distance from a given point called the "center." The distance from the center of the circle to its outline is called the "radius." Any straight line drawn from the center of the circle and terminating at its outline is also called a radius. The diameter of a circle is defined as the maximum distance from one side of a circle to the other and is twice the radius. This distance always



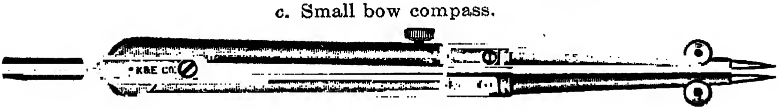
a. Large bow compass.



b. Beam compass.



c. Small bow compass.



d. Divider-type compass.
FIG. 1.16.

falls on a straight line drawn through the center of the circle, with both ends terminating at the outline of the circle; the term "diameter" is also applied to this straight line. The distance around the outline of a circle is called the "circumference" and is equal to 3.1416 times the diameter or 6.2832 times the radius. The ratio of the circumference to the diameter of a circle, 3.1416, is called "pi," for which the Greek symbol π is often used. An arc of a circle is any portion of the circumference. A tangent to a circle is a straight or sometimes curved line that just touches but does not pass through the circumference of a circle when the line is extended in either direction. A chord is

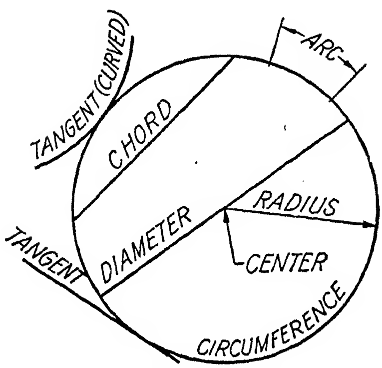


FIG. 1.17.—Terms of a circle.

FIG. 1.18.—Compass point.

a straight line drawn between any two points on the circumference of a circle. A diameter, therefore, is a special kind of a chord which passes through the center of the circle. The terms defined above are illustrated in Fig. 1.17.

Compass points, like pencil points, must be properly sharpened and must be kept always sharp to produce a uniformly wide and uniformly dark line. The compass lead is sharpened like a chisel-point pencil, with the flat side away from the needle point (see Fig. 1.18).

Soft lead should be used for making heavy lines, such as outlines, and a harder lead for construction lines. The exact hardness of lead will depend upon the work habits of the individual and the type of paper used, but the hardest lead that will produce the desired line is recommended so as to avoid smearing of the drawing. The compass is held in the right hand for adjustment, and the distance between the needle point and the lead is set, by aid of the 12-in. rule, to the radius of the desired circle (half the diameter). In setting the divider-type compass, one leg is held

between the first and second fingers and the other between the third and little fingers, using the thumb as a balance. The set screw of the bow-type compass is adjusted between the thumb and the second finger while held with the remaining fingers. A sample circle is then drawn and measured for accuracy. If the sample circle is not of the right diameter, the compass is readjusted and another circle drawn. This process is repeated until the precise diameter is obtained.

In drawing circles the same accuracy is required as in making any other part of an engineering drawing. To draw a circle or an arc, the needle point of the compass is placed exactly at the desired center and the compass is rotated by holding the knurled top between the thumb and the forefinger. The compass should be tilted slightly toward the direction in which the line is being drawn so that the twisting action will press the lead into the paper. It is suggested that practice circles be drawn to acquire skill in using the compass before it is used on actual problems, to be able to obtain a uniformly wide and black line, to prevent gouging unsightly holes in the paper with the point of the compass, and to prevent the needle point from moving, thus spoiling the circle. The needle point of the compass should be pressed into the paper no more than half the distance to the shoulder.

Exercise

1.8.1. Draw two lines intersecting at right angles. With the point of intersection as a center, draw seven concentric circles of ½, 1, 1½, 2, 2½, 3, and 3½ in. radii.

It is an easy operation to draw a straight line tangent to a circle but a very difficult operation to draw a circle tangent to one or more lines. The radius center lines, therefore, should be laid out first on a drawing and the circles drawn in lightly. The tangents may then be drawn lightly and the unwanted portion of the circle erased. The light lines may then be heavied up so that they blend into each other neatly and give the appearance of a single line.

Exercise

1.8.2. Draw the gusset[1] sketched in Fig. 1.19, using the dimensions given.

[1] The term "gusset" is applied to a triangular-shaped piece of sheet metal which is used to splice two members of a structure.

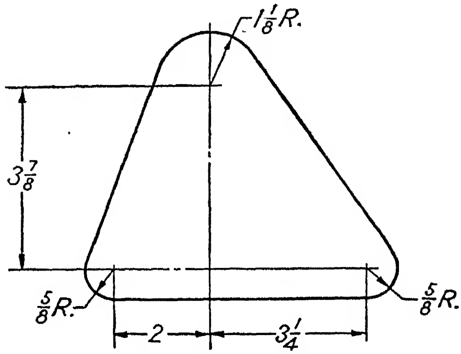


FIG. 1.19.—Gusset.

1.9. Use and Care of the Protractor.—An angle is defined as the amount of opening between two intersecting lines and is measured in degrees. An angle may be illustrated by the opening between the hour hand of a clock and a line corresponding to the hour hand's position at 12 o'clock, drawn on the face of the clock. If the hour hand is revolved to the 3 o'clock position, it

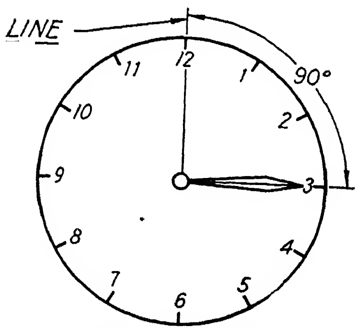


FIG. 1.20.—A 90-deg. angle.

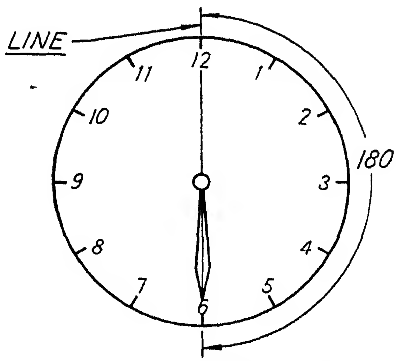


FIG. 1.21.—A 180-deg. angle.

makes an angle of 90 deg. with the line, commonly known as a right angle or a perpendicular (see Fig. 1.20). As the hour hand continues to rotate, the angle increases until, with the hour hand at the 6 o'clock position, the angle becomes 180 deg. (see Fig. 1.21). It should be noted that the hour hand and the line form a single straight line at this point. As the hour hand continues to rotate, the angle increases until the hour hand reaches the 12 o'clock position, at which time it has traveled through an

angle of 360 deg., or a complete circle (see Fig. 1.22). When the hour hand is at the 9 o'clock position, it has traveled through an angle of 270 deg., but the opening between the hand and the line is the same on the left side as it was when the hour hand was at the 3 o'clock position at the right side—or 90 deg. (see Fig.

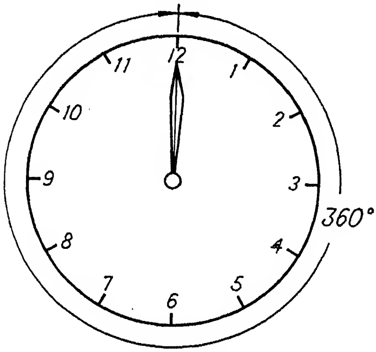


Fig. 1.22.—A 360-deg. angle.

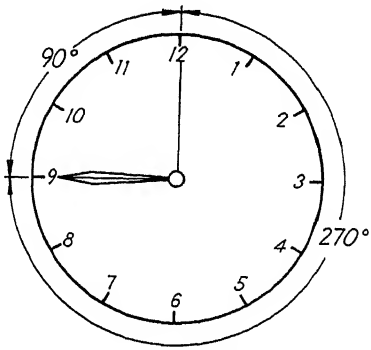


Fig. 1.23.—A 270-deg. angle.

1.23). When two lines meet at a point, it is evident that they actually form two angles, one of which is greater than 180 deg. and one less than 180 deg. (see Fig. 1.24). The angle which is less than 180 deg. is the one usually measured. The angle between the 1 o'clock and the 2 o'clock positions of the hour hand is one-third of 90 deg., or 30 deg.

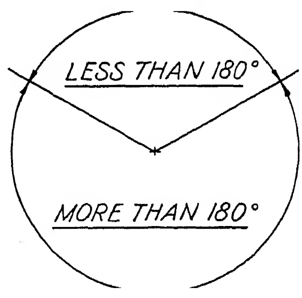


Fig. 1.24.—Angles formed by two lines.

Exercise

1.9.1. What angle is made by the hour and minute hands of a clock at the 3 o'clock position? 6 o'clock? 1 o'clock? 4:30 o'clock? 3:30 o'clock?

Angles are measured and laid out with the aid of a protractor. A drafting protractor is usually made of a thin sheet of transparent material in the shape of a half circle, the circumference of which is divided into 180 or 360 equal spaces, depending upon whether the markings represent 1 or ½ deg. spaces. The transparent-type protractor is always used with the marked side next to the paper. Figure 1.25 illustrates the method of measuring an angle *AOB*. The protractor is adjusted so that the line

on the protractor connecting the 0-deg. mark and the 180-deg. mark coincides with one leg of the angle *AO*, and the center point of the protractor lies at the vertex *O* of the angle. The number of degrees in the angle is determined by noting that line *OB*

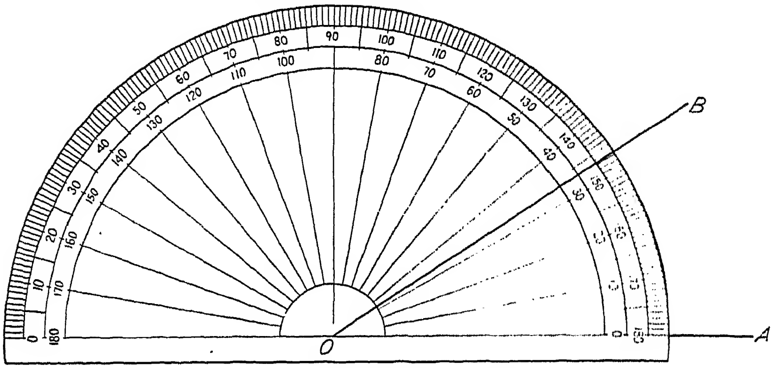


Fig. 1.25.—Measuring an angle.

crosses the markings of the scale midway between the 33-deg. mark and the 34-deg. mark, making the angle 33½ deg. The inner series of numbers is used, since leg *AO* passes through the zero mark of the inner series. If the protractor were adjusted

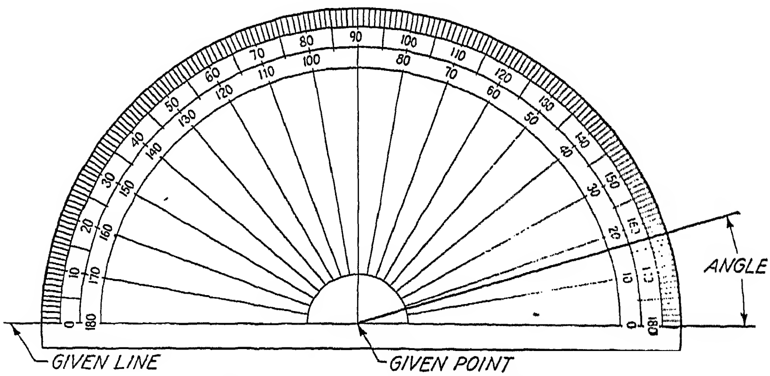


Fig. 1.26.—Constructing an angle.

so that one leg of the angle passed through the 0 mark of the outer series of numbers, the value of the angle would be determined by the intersection of the other leg with the outer series of numbers. If the legs of the angle are too short to reach from the center of the protractor to the graduation on its circumference, the legs

of the angle should be extended by drawing faint lines of sufficient length to read the value of the angle on the protractor.

If it is desired to construct a given angle at a given point on a given line, the protractor is adjusted so that the given line coincides with the 0- and the 180-deg. marks of the protractor, and the center point of the protractor falls on the given point (see Fig. 1.26). A thin, light pencil mark is made opposite the division of the protractor representing the required angle, the protractor is removed, and a line is drawn connecting the mark and the given point. This line may then be extended as far as required.

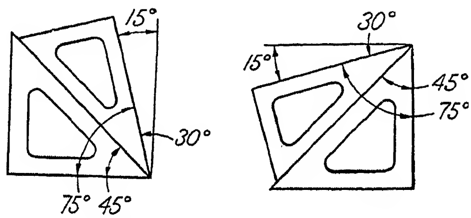


FIG. 1.27.—Constructing 15-deg. and 75-deg. angles.

The following angles may be drawn using the T square, the 45-deg. triangle, and the 30–60-deg. triangle: 15, 30, 45, 60, 75, 90 deg., and larger angles, in 15-deg. steps. Horizontal and vertical lines drawn by the T square and the triangles, and diagonal lines drawn on the sloping surface of the triangles will form all except 15- and 75-deg. angles. These latter two angles are formed by using both the 30–60-deg. and 45-deg. triangles as shown in Fig. 1.27.

Exercise

1.9.2. Draw a circle 4 in. in diameter and draw 12 lines passing through the center of the circle and touching its circumference, each making an angle of 15 deg. with the next; use only the T square and the triangles (see Fig. 1.28).

A ring of holes equally spaced around a circle may be laid out by dividing the circle into equal parts, using the protractor. The angle between the center lines of the holes is determined by dividing 360 deg. by the number of holes. Thus, if six holes are to be spaced equally around a circle, they will be spaced $^{360}/_{6}$ or 60 deg. apart.

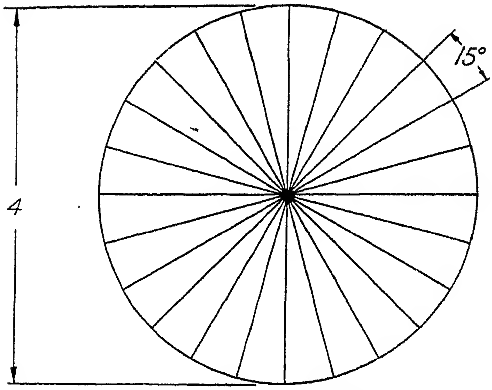


Fig. 1.28.—Dividing a circle into 24 equal parts.

Exercise

1.9.3. Using a protractor, lay out 10 holes 1/4 in. in diameter and equally spaced around a circle 5 in. in diameter.

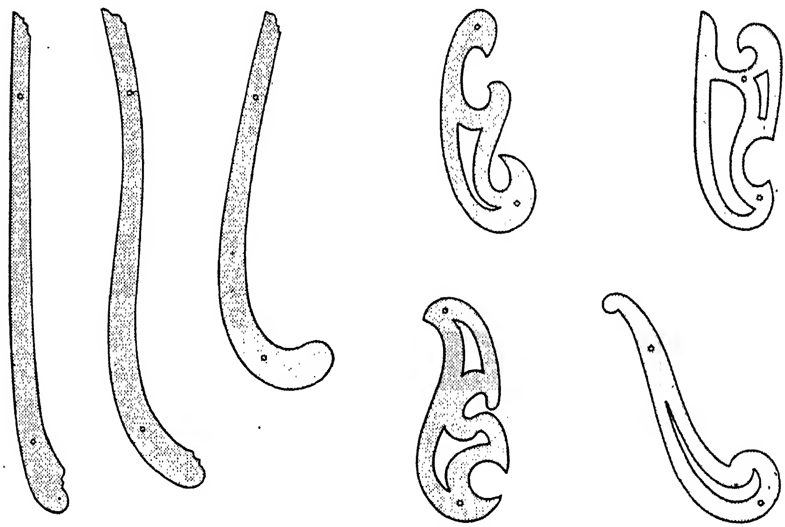


Fig. 1.29.—Irregular curves.

1.10. Use and Care of the Irregular Curves.—To draw a curved line through a series of points, an irregular or French curve is used. It is usually made of thin, transparent material cut so that the edges form a smooth line of gradually changing curvature. Various types of irregular curves are shown in Fig.

1.29. The curve is adjusted until it touches as many adjacent points as possible, but in no case fewer than three. Best results will be obtained if the curve is laid on the points so that both the points and the curve increase in curvature, as shown in Fig. 1.30.

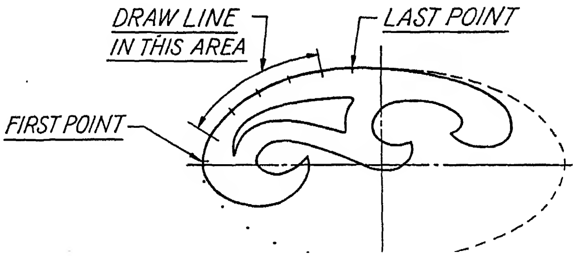


FIG. 1.30.—Use of irregular curve.

When the curve is adjusted, a line is drawn through the points it touches but not so far as the first or last points. The curve is readjusted until it is tangent to the first line drawn and until it passes through as many additional points as possible, and the line is continued but not so far as the last point. This procedure is repeated until the entire curved line is drawn.

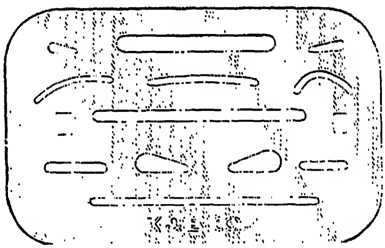


FIG. 1.31.—Erasing shield.

Exercise

1.10.1. On a piece of drawing paper, approximately 11 by 15 in., draw a horizontal line 1 in. above the bottom of the paper and a vertical line 1 in. from the left-hand edge of the paper. Lay out points, using the values given in Table 1.1. The horizontal distance is measured to the right of the vertical line on the horizontal line, and the vertical distance is measured upward from that point on the horizontal line. Connect these points, using an irregular curve. The first point in the table will be found by measuring to the right of the vertical line $1\frac{1}{2}$ in. and upward from the horizontal line $4\frac{1}{2}$ in.

1.11. Erasing Technique.—Fairly hard erasers, such as a "Ruby," are used to remove unwanted or incorrect pencil lines. To confine the erasing to the desired area, an erasing shield such as that shown in Fig. 1.31 is used. The erasing shield is a thin steel sheet with holes of different sizes and shapes. The hole

of appropriate shape is placed over the area to be erased, thus protecting the rest of the drawing. It will be noted that the portion of the paper on which an erasure has been made does not present so good a drawing surface as new paper, and special care should be taken in drawing lines over an erased area to keep them uniform with those on the remainder of the drawing.

TABLE 1.1

Point No.	Horizontal distance	Vertical distance	Point No.	Horizontal distance	Vertical distance
1	1 1/2	4 1/2	21	11 1/2	4 1/2
2	1 17/32	4 15/16	22	11 15/32	4 1/16
3	1 19/32	5 11/32	23	11 13/32	3 21/32
4	1 7/8	6 1/32	24	11 1/8	2 31/32
5	2 3/16	6 17/32	25	10 13/16	2 15/32
6	2 1/2	6 29/32	26	10 1/2	2 3/32
7	3	7 11/32	27	10	1 21/32
8	3 1/2	7 11/16	28	9 1/2	1 5/16
9	4 15/32	8 5/32	29	8 17/32	27/32
10	5 19/32	8 7/16	30	7 13/32	9/16
11	6 1/2	8 1/2	31	6 1/2	1/2
12	7 13/32	8 7/16	32	5 19/32	9/16
13	8 17/32	8 5/32	33	4 15/32	27/32
14	9 1/2	7 11/16	34	3 1/2	1 5/16
15	10	7 11/32	35	3	1 21/32
16	10 1/2	6 29/32	36	2 1/2	2 3/32
17	10 13/16	6 17/32	37	2 3/16	2 15/32
18	11 1/8	6 1/32	38	1 7/8	2 31/32
19	11 13/32	5 11/32	39	1 19/32	3 21/32
20	11 15/32	4 15/16	40	1 17/32	4 1/16

1.12. Blank Drawing Forms.—Most companies supply the draftsman with a printed drawing form. The size and the printed material vary greatly but the latter usually includes the name of the company, the drawing title, the drawing number, some designation as to the size of the drawing (usually coded in the drawing number), other groups responsible for information on the drawing, the material of the part drawn, the scale of the drawing, etc.

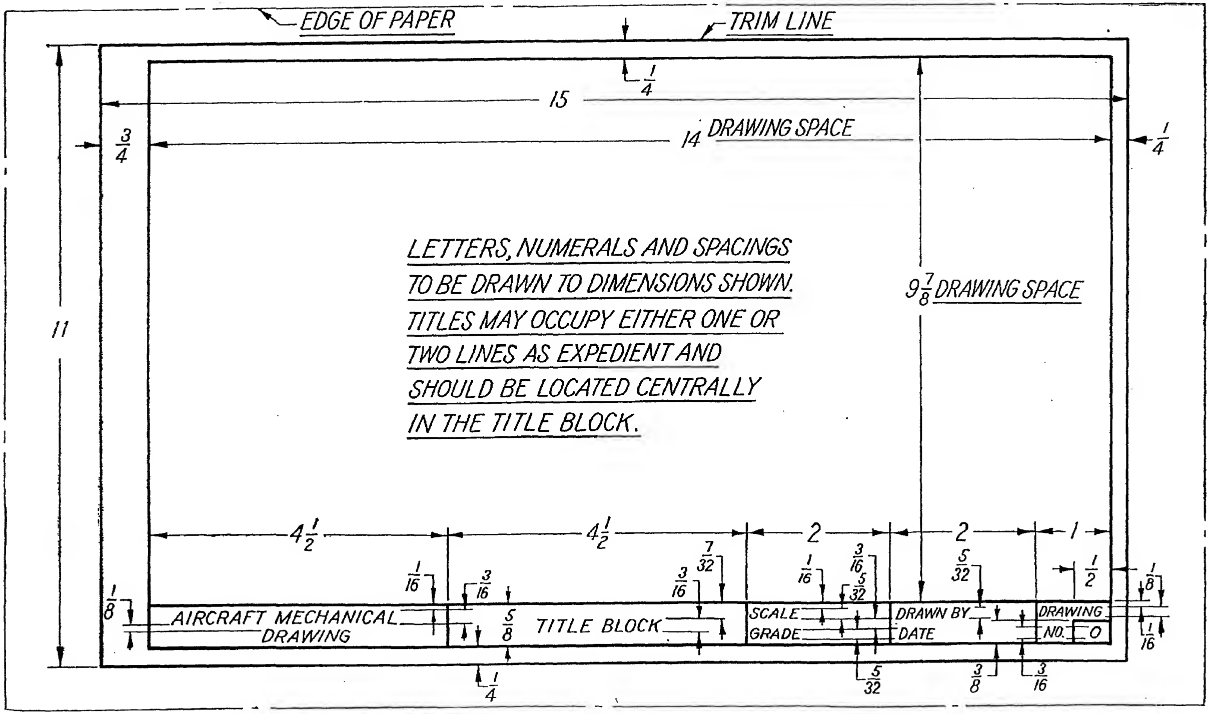


Fig. 1.32.—Standard drawing form.

Figure 1.32 shows the form suggested for the student's use. A piece of paper roughly 12 by 18 in. should first be attached to the drawing board and the border, trim, and title block lines drawn to the dimensions shown in Fig. 1.32. The drawing or exercise should be located centrally in the drawing space and completed before the title block at the bottom of the form is filled in. The drawing title will usually be indicated on the sketch or in the exercise description. If no title is furnished, the student should assign one that describes the part according to its use rather than according to its material. For example, a cast-metal bracket should be called a bracket rather than a casting.

In aircraft work, the title is written with the basic description of the part—usually a single word—followed by a dash and by further description of the part, thus: Doubler—Tank Access Door; Bulkhead—Fuselage Station 439; Bracket—Control Column Left Hand Hinge. To translate the titles into ordinary English, begin after the dash and read the word before the dash last, thus: Tank access door doubler. This peculiar arrangement of drawing titles facilitates the cataloguing and indexing of parts by title.

In the space labeled "Scale" fill in "Scale—Full Size" (or "Half Size," "Quarter Size," or "Double Size," as the case may be). The scale of a drawing is the relation the size of the picture bears to the actual size of the object it represents. In a full size drawing the picture is exactly the same size as the object. In a quarter size drawing the picture is one-fourth as large as the object it represents. In making a quarter size drawing, a distance of 1 in. on the object would be laid out on the drawing as ¼ in.; a length of 10 in. would be laid out on the drawing as 2½ in. In a double size drawing, the picture is twice as large as the object it represents.

The grade of the drawing should be determined by the instructor. The draftsman should fill in his name after "Drawn By," together with the date of the completion of the drawing. The draftsman should use both his first name or initial and his last name to provide accurate identification. The numbering of the drawings should begin with one and follow consecutively. The paper outside the trim line may be used conveniently for sketching, making test circles, checking pencil lines, etc. The drawing

paper should always be placed with the long side parallel to the bottom of the drawing board rather than to the side, with the title block along the bottom of the paper. After the drawing has been completed, it should be taken from the board and the excess paper outside the trim line should be removed.

CAUTION.—Never use a knife or razor blade against the T square or the triangles or on the surface of the drawing board, since this might ruin these instruments.

1.13. General Hints and Precautions.—After a drawing is completed, dirty or smeared spots may be cleaned up by means of an Artgum eraser. In this regard, great care should be exercised to keep hands and drawing instruments clean. Triangles, irregular curves, protractors, erasing shields, and hands should be washed frequently with soap and water. Pencils and compasses should be wiped clean of lead filings, and above all, pencils and compasses should never be sharpened over the drawing. The mill file or sandpaper board should never be placed on the drawing or on the drawing board, and the drawing board surface itself should be either washed or kept covered with clean paper. One cause of messy drawings is a drawing board surface lined with the imprint of previous drawing lines, which deflect the pencil or compass from its true course. It should be emphasized that good drawings are produced by good drawing instruments in the hands of a draftsman who has acquired skill in using his equipment and who constantly tries to produce the best possible work.

It is suggested that the student refer to the instructions regarding the use of instruments as problems involving the use of these instruments arise.

1.14. Problems.—Divide the standard drawing form into four equal rectangles by drawing one vertical and one horizontal line through the middle of the drawing space. Four of the exercises shown below may then be drawn on each sheet, except for Exercise 1.14.13. The plates should be titled "Drawings 1 to 4, Instruments—Exercise in the Use of." The parts should be carefully drawn to scale and should be located in the center of the space provided for them. In problems involving the use of the compass, the center of the radius should be located first, then the arc drawn, and the straight lines connecting the radii drawn last, as noted in Sec. 1.8. It should be observed that the figures shown below are sketches and are not to scale, the size of the part being determined by the dimensions given on the sketches. The dimensions shown on the sketches need not be duplicated on

the actual drawing, since they are to indicate how the part is to be drawn and are not necessarily in good form.

1.14.1. (Fig. 1.33)

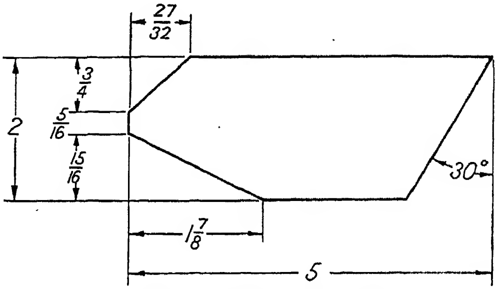


FIG. 1.33.—Doubler—wing skin.

1.14.2. (Fig. 1.34)

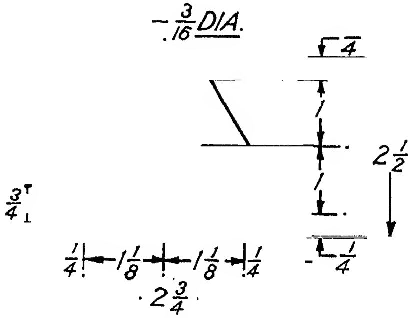


FIG. 1.34.—Gusset—longeron splice.

1.14.3. (Fig. 1.35)

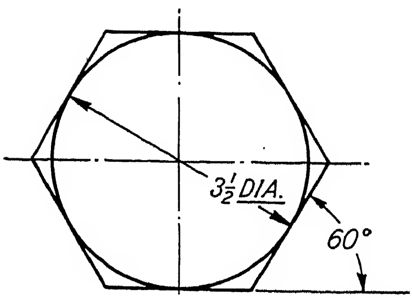


FIG. 1.35.—Hexagon—circumscribed.

1.14.4. (Fig. 1.36)

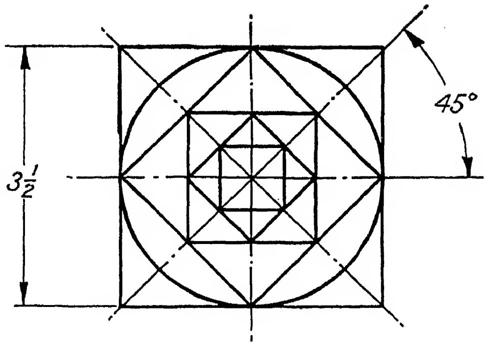


FIG. 1.36.—Squares—circumscribed and inscribed.

1.14.5. (Fig. 1.37)

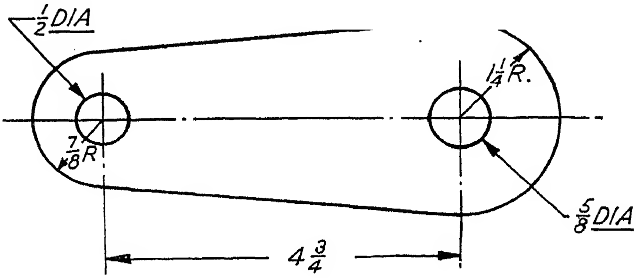


FIG. 1.37.—Link—gust lock.

1.14 6. (Fig. 1.38)

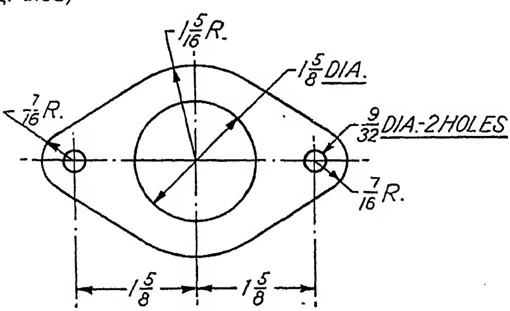


FIG. 1.38.—Gasket—oil drain.

1.14.7. (Fig. 1.39)

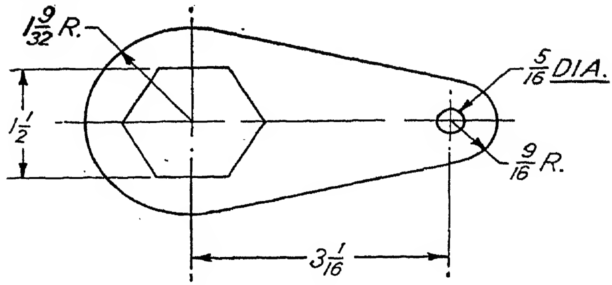


FIG. 1.39.—Lock—landing gear pin.

1.14.8. (Fig. 1.40)

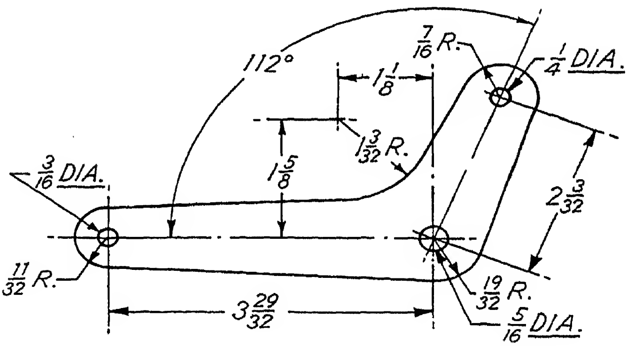


FIG. 1.40.—Bellcrank—emergency brake.

1.14.9. (Fig. 1.41)

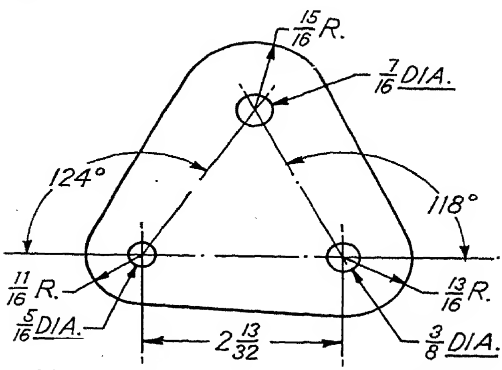


FIG. 1.41.—Yoke—trim tab control.

1.14.10. Measuring the "Horizontal Distance" from the left-hand edge of the drawing space and the "Vertical Distance" from the bottom edge of the drawing space, lay out the points, offsets for which are given in Table 1.2, and draw a curve through them, using an irregular curve (refer to similar exercise in Sec. 1.10).

TABLE 1.2

Point No.	Horizontal distance	Vertical distance	Point No.	Horizontal distance	Vertical distance
1	1/2	4	7	2 9/16	25/32
2	5/8	3 3/16	8	3 3/8	19/32
3	25/32	2 9/16	9	4 1/4	15/32
4	1	2	10	5	13/32
5	1 13/32	1 7/16	11	6 13/32	5/16
6	1 15/16	1 1/32			

1.14.11. Lay out points the offsets of which are given in Table 1.3, and draw a curve through them, following the procedure of Exercise 1.14.10.

1.14.12. Check by drawing an arc of a circle with a 4 in. radius, and using as a center a point 1 1/2 in. to the right of the vertical edge and 1/2 in. up from the bottom edge of the drawing space. How does the first curve compare with the arc in smoothness?

TABLE 1.3

Point No.	Horizontal distance	Vertical distance	Point No.	Horizontal distance	Vertical distance
1	5 1/2	1/2	6	3 11/16	3 27/32
2	5 7/16	1 7/32	7	2 31/32	4 7/32
3	5 3/16	2 1/16	8	2 7/32	4 7/16
4	4 13/16	2 3/4	9	1 1/2	4 1/2
5	4 5/16	3 11/32			

1.14.13. Using a full standard drawing form, lay out the points in Table 1.4 and connect them with a smoothly faired line. This figure is an airfoil[1] or cross section of an airplane wing.

TABLE 1.4

Point No.	Horizontal distance	Vertical distance	Point No.	Horizontal distance	Vertical distance
1	$12\frac{1}{2}$	5	20	$2\frac{1}{2}$	5
2	$11\frac{15}{16}$	$5\frac{1}{8}$	21	$2\frac{9}{16}$	$4\frac{29}{32}$
3	$11\frac{13}{32}$	$5\frac{7}{32}$	22	$2\frac{5}{8}$	$4\frac{27}{32}$
4	$10\frac{1}{2}$	$5\frac{3}{8}$	23	$2\frac{3}{4}$	$4\frac{25}{32}$
5	$9\frac{15}{32}$	$5\frac{17}{32}$	24	$3\frac{1}{32}$	$4\frac{11}{16}$
6	$8\frac{17}{32}$	$5\frac{21}{32}$	25	$3\frac{5}{16}$	$4\frac{5}{8}$
7	$7\frac{7}{16}$	$5\frac{25}{32}$	26	$3\frac{1}{2}$	$4\frac{19}{32}$
8	$6\frac{3}{4}$	$5\frac{27}{32}$	27	$3\frac{29}{32}$	$4\frac{17}{32}$
9	$5\frac{1}{2}$	$5\frac{29}{32}$	28	$4\frac{13}{32}$	$4\frac{15}{32}$
10	5	$5\frac{29}{32}$	29	$4\frac{11}{16}$	$4\frac{7}{16}$
11	$4\frac{1}{4}$	$5\frac{7}{8}$	30	$5\frac{1}{2}$	$4\frac{13}{32}$
12	$3\frac{15}{16}$	$5\frac{27}{32}$	31	$6\frac{1}{2}$	$4\frac{13}{32}$
13	$3\frac{7}{16}$	$5\frac{3}{4}$	32	$7\frac{1}{4}$	$4\frac{7}{16}$
14	$3\frac{1}{4}$	$5\frac{11}{16}$	33	$8\frac{21}{32}$	$4\frac{17}{32}$
15	3	$5\frac{19}{32}$	34	$9\frac{21}{32}$	$4\frac{5}{8}$
16	$2\frac{3}{4}$	$5\frac{7}{16}$	35	$10\frac{1}{2}$	$4\frac{23}{32}$
17	$2\frac{5}{8}$	$5\frac{11}{32}$	36	$11\frac{1}{2}$	$4\frac{27}{32}$
18	$2\frac{17}{32}$	$5\frac{7}{32}$	37	12	$4\frac{29}{32}$
19	$2\frac{1}{2}$	$5\frac{1}{8}$	38	$12\frac{1}{2}$	5

[1] Dimensions derived from NACA TR610 Fig. 19 for 23015 Airfoil.

CHAPTER 2

LETTERING

2.1. Uses and Objectives of Lettering.—By orthographic projection, a picture or a diagram of a physical part of an airplane is produced. In order to fabricate such a physical part, further information in the way of notes, dimensions, materials and specifications, quantities required, subassemblies, etc., must be added to the drawing. To supply this printed information, the draftsman must develop skill in lettering.

The first requirement of good lettering is accuracy. Since the lettered information on a drawing is just as necessary to the fabrication of a part as the picture of the part itself, the lettering must be so clear that there is no possibility of misinterpretation. If the number 5 is mistaken by the mechanic for the number 7, he may fabricate parts of an incorrect length which would have to be scrapped, with the attendant waste of material, machine time, and man power.

The second requirement of good lettering is speed. The value of a draftsman to an engineering department is based on the quantity of accurate work he can turn out in a day. Other things being equal, the draftsman who can letter rapidly is more valuable than the draftsman who letters slowly.

Artistry in lettering is not highly valuable in the aircraft industry. Lettering should be neat and easy to read but need not be beautiful. In certain types of drawing such as architectural drafting, where the drawing is used as a sales medium, artistry is valuable. There, the lettering, as well as the representation of landscaping, is used to enhance the beauty of the structure actually depicted. In aircraft work, the sole purpose of lettering on a drawing is to convey information from the engineer to the mechanic; it should primarily be legible and subject to no possible misinterpretation. Ornamental lettering should be strictly avoided.

2.2. General Technique.—Lettering is always done freehand, but horizontal guide lines drawn very faintly on the paper are

used to keep the letter heights uniform and to keep the notes from sloping upward or downward. To save drawing time, draftsmen usually prepare a set of guide lines on a separate sheet of heavy paper, which is slipped under the drawing; the guide lines may be seen through the semitransparent drawing paper while lettering, after which the heavy guide-line paper is removed. All notes on a drawing are made to stand out by the use of underlines, *i.e.*, a heavy line drawn under the entire length of the note and approximately $\frac{1}{16}$ in. below the bottom of the letters (see Fig. 2.1).

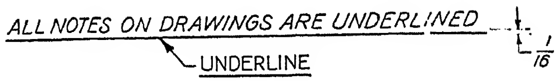


FIG. 2.1.—Use of underlines.

The grade of pencil selected for lettering should be as hard as the draftsman can use conveniently to prevent the lettering from smearing the drawing and from fading out with wear. However, the pencil grade must be sufficiently soft so that the lettering will be dense black and will stand out sharply on the blueprint copy of the drawing. A grade H pencil is recommended for average use, although individual preference may dictate the selection of either a harder or a softer grade of pencil. A dull pencil should never be used for lettering as neither should a needle-fine pencil point. After every few letters, the pencil should be rotated to prevent the point from wearing flat. Considerable pressure should be used on the pencil, but, unlike lines, letters should never be traced over, since it is practically impossible to make the second line coincide with the first line.

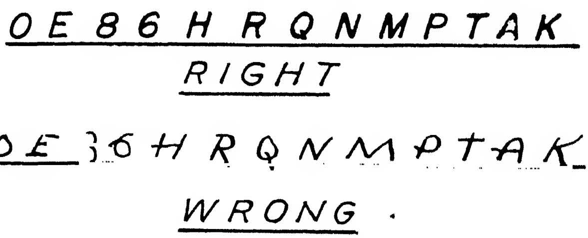


FIG. 2.2.—Joining letters.

Example.—Draw a straight line approximately ½ in. long freehand, and trace over it once. Note how the width and blackness of the line vary. The width of lines forming letters should be kept uniform; care should be

exercised that joining lines fair smoothly into each other, and that lines which should meet do not overrun nor stop short of their intersection (see Fig. 2.2).

2.3. Forming Letters.—Aircraft lettering consists entirely of capital letters which may be either vertical or slant. The type that the individual finds best for clarity and speed should be

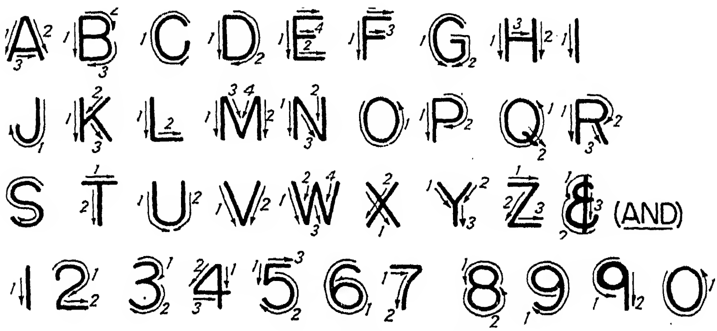


FIG. 2.3.—Vertical lettering.

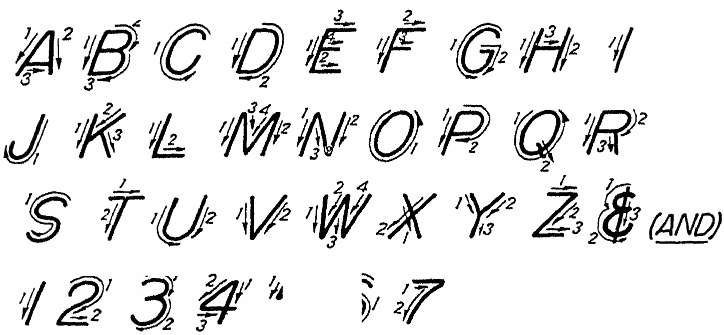


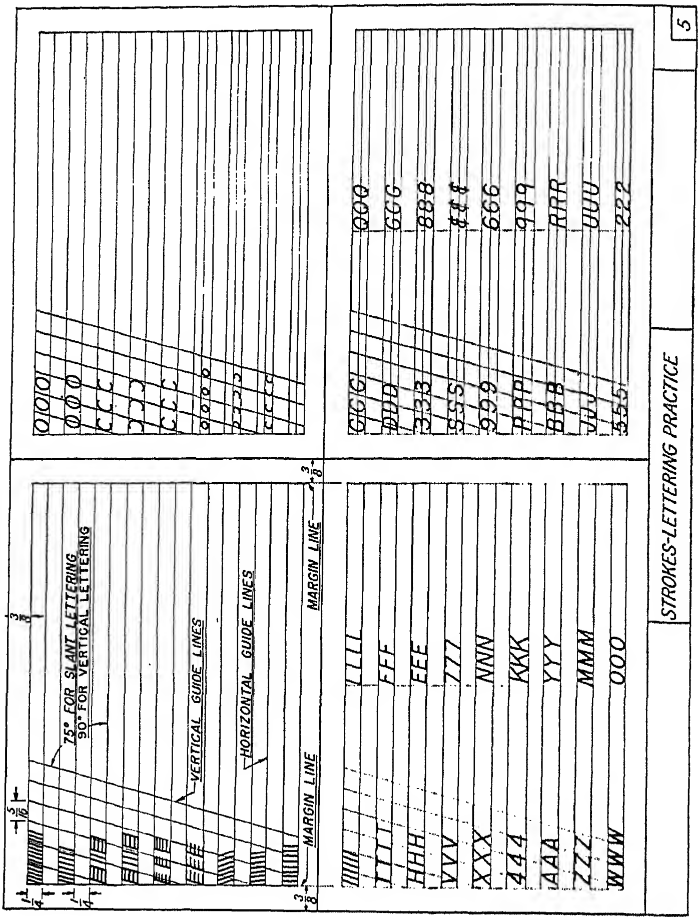
FIG. 2.4.—Slant lettering.

selected, but slant and vertical lettering should not be combined on one drawing. Figures 2.3 and 2.4 illustrate the methods of constructing vertical and slant letters. These methods are recommended, but, should alternate methods be found more desirable, they may be used.

Exercise

2.3.1. Drawing 5, Strokes—Lettering Practice.—Lay out an 11 by 15 in. standard drawing form, as shown in Fig. 2.5. The dimensions shown in the upper left-hand quarter of the drawing apply to all four quarters. These

dimensions are to assist in laying out guide and margin lines but should not be copied on the drawing plate. A sharp 4H pencil should be used for guide and margin lines so that they will be very faint. In contrast, the remainder of the line work on the drawing should be made with a 2H pencil, using



heavy pressure and not too sharp a point to produce heavy black lines. Intermediate horizontal guide lines should be drawn as shown, and a half dozen vertical guide lines at the left-hand side of each quarter section of the drawing should be drawn with a 4H pencil. Fill each line with the letters or lines in Fig. 2.5, starting at the top left-hand side of the drawing and

using the guide lines. All strokes and letters are to be drawn freehand; care should be exercised to make the strokes and letters just touch the top and bottom guide lines but not pass through them.

2.4. Using Letters in Words and Sentences.—Once skill in forming individual letters is developed, the letters must be combined into words, phrases, and sentences, which will convey

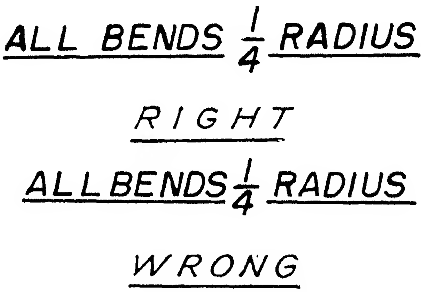


FIG. 2.6.—Spacing words.

information to the shop technician in the form of drawing notes and dimensions. The spacing between letters within a word should be kept small and uniform, and the spacing between words should be kept large (see Fig. 2.6). The words in the note on

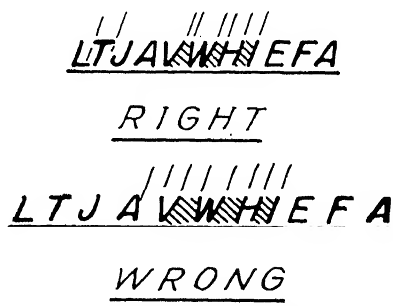


FIG. 2.7.—Spacing letters.

the top stand out and may be read at a glance. The note on the bottom must be studied.

Letters will appear evenly spaced within a word if the area of white paper between the letters is the same. Due to the difference in the shapes of adjacent letters, this uniform spacing effect cannot be accomplished by keeping the same distance between the end of one letter and the beginning of the next. Some combinations, such as HE, must be kept well separated, while

some combinations, such as LT, must be kept close together, even to the point of overlapping slightly, in order to make the letters appear evenly spaced (see Fig. 2.7).

Slope, height, and width of letters should be uniform as well as width and blackness of the lines forming the letters (see Fig. 2.8).

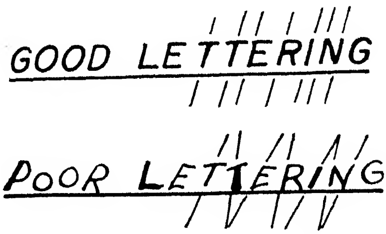


FIG. 2.8.—Appearance of letters.

For keeping the spacing, the slope, and the blackness of lines uniform, it is suggested that the draftsman glance frequently at the letters just previously formed.

FIG. 2.9.—Forming letters.

As the technique of lettering improves, attention should be given to developing speed without sacrificing accuracy. A common error, which creeps in with the development of speed, is carelessness in forming the curls on such letters and figures as 5, 3, S, C, G, and 2 (see Fig. 2.9).

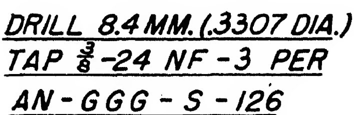


FIG. 2.10.—Spacing letters in notes.

2.5. Notes.—Since the purpose of notes on an aircraft drawing is to convey information from the designer to the builder, the notes should be as simple as possible. They should be short, concise, expressed in everyday language, and subject to no possible misinterpretation. Notes are arranged in blocks near the operation that they describe. Each line in the block should be a phrase, if possible, and each line should start directly and end approximately below the line above. In Fig. 2.10 the first line contains 16 letters, the second line 12 letters, and the last

line 9 letters, yet all lines are nearly the same length. Notes may be expanded or squeezed into a smaller space by using wider or narrower letters with the space between them kept in proportion (see Fig. 2.11).

FIG. 2.11.—Spacing letters in words.

All notes and figures on aircraft drawings are read from the bottom of the drawing so that the user does not have to revolve the drawing to read the figures or notes (see Fig. 2.12). Lettering for notes, whole numbers, and decimal fractions should be from $\frac{1}{8}$ to $\frac{5}{32}$ in. high (see Fig. 2.13). Common fractions and tolerances should be $\frac{3}{32}$ to $\frac{1}{8}$ in. high. Common fractions are always written thus, $\frac{5}{32}$, and never with the bar diagonally, thus, 5/32. For these smaller figures a sharper pencil should be used to make them easily legible (see Fig. 2.14). The title

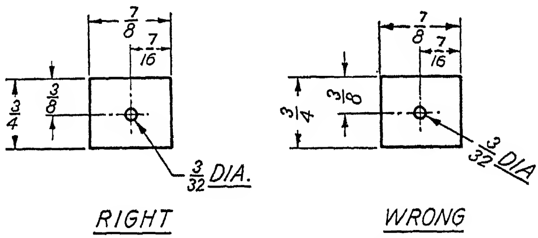


FIG. 2.12.—Direction of lettering.

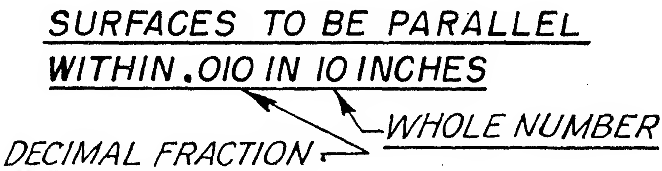


FIG. 2.13.—Notes, numbers, and decimal fractions.

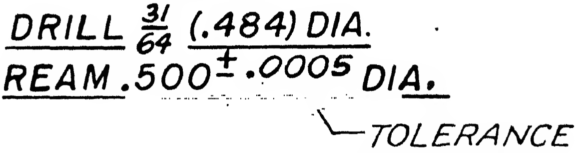


FIG. 2.14.—Common fractions and tolerances.

of a drawing should be $\frac{3}{16}$ in. high without the underlines (see Fig. 2.15). Sections and views are referred to by means of

BRACE-RUDDER PEDAL SUPPORT

FIG. 2.15.—Drawing titles.

$\frac{3}{8}$ in. high letters blocked in solidly (see Fig. 2.16). In notes consisting of two or more lines, a space approximately equal to the height of the letters separates each line. After some experi-

SECTION **A-A**

FIG. 2.16.—Section and view identification.

ence in lettering has been gained, the spacing of the guide lines, which determines the height of the letters, should not be laid out with a rule but should be judged by eye. An occasional check with the rule will point out errors in judging guide-line spacing and letter height.

Proficiency in lettering can be developed only by faithful and regular practice. Fifteen minutes each day will be much more effective than two hours once a week. Additional lettering practice may be gained if lettering is used in place of longhand for everyday writing when speed is not required. All lettering should be scrutinized to see where improvement could be made.

Exercise

2.5.1. Listed below are a series of notes used extensively in aircraft drawings:

TYPICAL AIRCRAFT NOTES

First Column: General Notes

1. All bend radii $\frac{3}{16}$
2. All bend reliefs $\frac{5}{32}R$
3. Drill 30 (.128) dia.
   for all $\frac{1}{8}$ rivets
4. AN 430 AD4 rivets
   approx. 30 req.
5. AN 426 AD4 rivets
   approx 45 req.
6. Minimum edge distance
   twice rivet diameter
7. Rivets shown thus:
   are field rivets & are to
   be driven on installation

8. Std. tolerances do not apply to rivet spacing. Unless otherwise specified dims. given are maximum
9. Drill $\frac{.193}{.200}$ dia. for all 3/16 dia. bolts & screws
10. Heat treat harden all soft stock per AN-QQ-H-186
11. f indicates smooth machine finish
12. Dims. marked thus * are approximate. To be determined on first airplane and engineering dept. notified
13. All spot welds approx. 5/8 O.C.

Second Column: General Notes

1. All fillets 3/16*R*.
2. All webs 5/32
3. All cast corner radii 1/16
4. Surfaces marked thus ⊗ to be cast smooth and flat without draft
5. Casting to be straightened by foundry

5149632 L.H. shown
5149632-1 R.H. opposite

Symmetrical about ℄
Left side shown
Right side opposite

All diameters marked thus: ∈
must be concentric within
.002 full indicator reading

3217743 bracket 1 req.

Drill $\frac{.250}{.254}$ dia. 2 places

Spotface 9/16 dia. 2 places for
AN 4-12A bolt 2 req.
AN 960-416 washer 2 req.
AAF365-428 nut 2 req.

Joggle .062 × 13/16

Third Column Ream 1.250 ± .0005
Press in AN 200 K5
Bearing 1 req.
Retain by staking 4 places
Drill 15/64 (.234) dia. thru

Ream .250 ± .0005 dia. depth $\frac{9}{16}$

Drill $\genfrac{}{}{0pt}{}{.375}{.379}$ dia. × $1\frac{1}{4}$ deep

C'drill $\genfrac{}{}{0pt}{}{.500}{.504}$ dia. × $\frac{7}{16}$ deep

C'sink 110° × $\frac{9}{16}$ dia.

Chamfer 45° × $\frac{1}{32}$
Thread $\frac{3}{8}$-24 NF-3
Per Spec. AN-GGG-S-126

Drill $\frac{23}{64}$ (.3594) dia. depth $\frac{7}{8}$
C'drill $\frac{1}{2}$ dia. depth $\frac{1}{4}$
Tap $\frac{7}{16}$-14 NC-3 depth $\frac{3}{4}$
Per spec. AN-GGG-S-126

Drill $\frac{3}{8}$ (.375) dia. thru
C'drill "Z" (.413) dia. depth $\frac{15}{32}$
C'sink 90° × $\frac{9}{16}$ dia.
Taper ream $\frac{3}{4}$ per foot
to $\genfrac{}{}{0pt}{}{.442}{.454}$ dia. at
large end of taper
Tap $\frac{1}{4}$ pipe thread per
Spec. AN-GGG-P-363

Lay out an 11 by 15 in. standard drawing form titled "Drawing 6, Notes—Common Aircraft Drawing." Using a 4H pencil, lay out faint horizontal guide lines spaced $\frac{5}{32}$ in. apart. Leave $\frac{3}{8}$ in. between the margin lines of the drawing and the horizontal guide lines on all four sides. Letter the above notes in $\frac{5}{32}$ in. letters, either vertical or slant; arrange in blocks as shown above, leaving one space between each line within a block and three spaces between each block. Draw a faint vertical guide line $4\frac{7}{8}$ in. from the left-hand margin of the drawing for the beginning of the second column of notes and another vertical guide line $9\frac{3}{8}$ in. from the left-hand margin line for the beginning of the third column of notes.

2.6. Common Errors.—Carelessly formed letters or figures may be mistaken for others similar to them, with a resultant misinterpretation of the drawing. Most frequent confusion arises between the letter S and the figure 5. A carelessly formed letter, thus S, may be interpreted either as a 5 or an S. Since the lower halves of the letters are identical, the upper halves must be sharply contrasted thus, 5 S. The top two lines of the five are quite straight while the top of the S is smoothly rounded and finished with a slight downward curl. A carelessly formed 5 may also be mistaken for a 6, thus 5. Again keeping the top two lines quite straight, and further keeping the bottom curve open, will distinguish between the two figures.

A common error is partially closing the "eyeholes" of letters and figures, thus, 3, which looks like an 8 or B; C, which looks like an 0; S, which looks like an 8; 9, which looks like an 8. A carelessly made figure 4, 4, appears to be an A and vice versa. Carelessly formed D and O may be mistaken for each other, O; as may be Q and R, R; G and C, G; 6 and 0, O; 7 and 4, 4. The use of ornate letters or figures often contributes to such confusion. Variations from usual letters, such as 7, 4, 3, should be avoided. The forms described in Figs. 2.3 and 2.4 are so chosen as to permit the least similarity between different letters and figures.

Careless spacing of letters and words may lead to confusion. RADII $\frac{1}{8}$ may be read "radii $1\frac{1}{8}$" instead of "radii $\frac{1}{8}$"; 1OD. may be read "10 D." (diameter) instead of "1 O.D." (outside diameter). 13 may be read as B or 8 instead of 13. F E may be confused because the underline is too close to the F or it covers the bottom bar of the E. FAR. Is this word "ear" or "far"?

Exercise

2.6.1. Abbreviations—Standard Aircraft.—The abbreviations listed below are used most frequently in aircraft drawings. They have been selected from a list prepared by the American Standards Association and are in common usage in aircraft drafting. These abbreviations should be rigidly adhered to, but where there is any doubt as to whether the abbreviation will be understood, or if there is ample space, the term should be printed out in full rather than abbreviated.

Lay out Drawing 7 identically to Drawing 6, except draw six faint vertical guide lines $\frac{3}{8}$, $3\frac{7}{8}$, $4\frac{7}{8}$, $8\frac{3}{8}$, $9\frac{3}{8}$, and $12\frac{3}{8}$ in. from the left-hand margin. In the top space just to the right of the $\frac{3}{8}$, $4\frac{7}{8}$, and $9\frac{3}{8}$ in. lines, letter "term"; to the right of the $3\frac{7}{8}$, $8\frac{3}{8}$, and $12\frac{3}{8}$ in. lines, letter "abbreviation." Skip a line and letter the term and its abbreviation, using every other line, and underlining both the term and the abbreviation. Care should be exercised to make the letters extend from the top to the bottom of their respective guide lines without passing through the limits of the guide lines. The vertical guide lines should be used to begin each term so that when the plate is finished, three neat columns of terms and abbreviations will be produced.

Term	*Abbreviation*	*Term*	*Abbreviation*
aileron	ail.	assembly	assem.
alclad	alc.	bearing	brg.
aluminum alloy	alum. alloy	bracket	brkt.
approximate	approx.	bulkhead	blkd.

Term	*Abbreviation*
bushing	bush.
cadmium	cad.
canceled	can.
casting	cstg.
chrome-molybdenum	C.M.
circumference	circum.
commercial	coml.
concentric	∈
control surfaces	cont. surf.
counterbore	c'bore
counterdrill	c'drill
countersink	c'sink
diameter	dia.
dimension	dim.
drawing	dwg.
each	ea.
elevator	elev.
empennage	emp.
engine	eng.
equal	eq.
exhaust	exh.
extrusion	extr.
feet	ft.
flexible	flex.
foot	ft.
forward	fwd.
fuselage	fus.
gallon(s)	gal.
gauge	ga.
heat treat(ment)	H.T.
heel line	H.L.
horizontal	horiz.
hydraulic	hydr.
ignition	ign.
inboard	inbd.
inch(es)	in.
inclusive	incl.
inside diameter	I.D.
installation	instal.
instrument	instr.
landing gear	ldg. gr. or ldg. gear
layout	L.O.
left-hand	L.H.
lofted line	L.L.
longeron	long.
magnesium alloy	mag. alloy
material	matl.
maximum	max.
minimum	min.
minute(s) time	min.
molybdenum	moly.
mounting	mtg.
nacelle	nac.
number required	no. req.
obsolete	obs.
on center(s)	O.C.
outside diameter	O.D.
pitch diameter	P.D.
propeller	prop.
radiator	rad.
radius	R.
reference	ref.
requirements	reqmts.
right hand	R.H.
rudder	rud.
specification	spec.
spherical radius	spher. R.
stabilizer	stab.
standard	std.
steel	stl.
stock length	S.L.
stock width	S.W.
symmetrical	sym.
thread	thd.
trailing edge	T.E.
vertical	vert.

CHAPTER 3

GEOMETRY IN DRAWING

3.1. Introduction.—A knowledge of the fundamental principles of geometry will materially assist the draftsman in performing his work more quickly and with less effort. Geometry, as all mathematics, is a logical development of simple principles into more complex conclusions. Its foundation is a small number of axioms or fundamental truths and their corollaries or deductions from these fundamental truths. Examples of geometric axioms are: "A straight line is the shortest distance between two points." "If two straight lines coincide in part, they will coincide throughout their entire length." "Parallel lines are straight lines that will never meet no matter how far they are extended." A corollary which follows from this last axiom is: "If two straight lines do not meet no matter how far they may be extended, the two lines are parallel." These simple truths are then used to prove more complicated statements which, in turn, are used to prove still other statements or propositions.

By such logical developments are derived a number of principles which the draftsman uses constantly in his work. It is the application of these frequently used principles to drafting work that will be considered in the following, rather than geometrical developments with which the student may already be familiar. To save time and to improve accuracy in drafting work, many constructions are made by manipulation of drawing instruments rather than by more cumbersome geometric methods.

3.2. Definition of Terms.—Some of the terms pertaining to geometrical constructions, such as angles, circles, diameters, radii, circumferences, arcs, chords, and tangents, have been defined and discussed in Chap. 1. A plane is defined as a flat surface which has length and breadth but no thickness. The top surface of a flat table, one surface of a flat window, or the top of a smoothly frozen lake may be considered as examples of planes. Planes are convenient bases from which to measure

distances; in drafting practice these planes may be vertical, horizontal, or oblique.

Perpendicular and parallel lines and planes form the basis of most drawing work. The main view of an object is located so that the main planes and lines of the object are either perpendicular or parallel to the plane of the paper. In drawing a view of a rectangular block, one side of the block is represented in the plane of the paper, and the parallel side is represented as parallel to the plane of the paper. The four remaining sides of the block are shown as planes perpendicular to the plane of the paper. The edges formed by the intersection of the side planes of the block are represented in the view as straight lines either parallel or perpendicular to the plane of the paper. Auxiliary views are projected along perpendicular and parallel lines, and planes and all dimensions are taken in rectangular fashion, *i.e.*, perpendicular and parallel to the lines and the planes of an object.

Parallel lines and planes are everywhere the same distance apart. An example of parallel lines is the ruling on letter paper, or the lines on the lettering guide described in Chap. 2, or the opposite border lines of a drawing. The ceiling and floor of a building may be thought of as parallel planes, and an antenna wire or clothes line represents a line that is usually parallel to a plane, the ground. Parallel lines may be constructed by a geometrical procedure, but in drafting they are always drawn with a T square and a triangle, or with two triangles as described in Secs. 1.5 and 1.6, or by special drafting devices such as parallel rulers or a drafting machine.

A straight line is perpendicular to another straight line if their intersection forms a 90-deg. angle or right angle. Which angle of the four angles formed by the intersecting lines is 90 deg. is not specified, since if two straight lines intersect and one angle formed by the intersection is a right angle, the other three angles formed by the intersection are also right angles. If a line is perpendicular to a plane, all angles formed by that line and any line in the plane drawn to the point of intersection are right angles. A telephone pole may be thought of as a line perpendicular to a plane, the ground. If an infinite number of lines, each perpendicular to a given plane, intersect the given plane in a straight line, these lines will form a second plane perpendicular to the given plane. The top, bottom, and side

of a box are perpendicular planes. In drafting work, perpendicular lines are drawn using a T square and the 90-deg. angle of a triangle, or two triangles, as described in Sec. 1.6.

3.3. Relation of Lines and Angles.—It is of great assistance to the draftsman to be able to recognize the relation among angles within a drawing as well as some conclusions drawn from these relations. If two straight lines intersect forming four angles, the angles opposite each other are equal. In Fig. 3.1, angle A equals angle C, and angle B equals angle D. Also, the sum of the two angles adjacent to each other is equal to 180 deg., since the two angles together form a straight line. In Fig. 3.1, the sum of angle A and angle B equals 180 deg. as does the sum of angle B and angle C, C and D, and D and A. These two principles are constantly used in dimensioning angles on a drawing, because other dimensions or the outline of the object itself may interfere with placing the dimension where the angle is shown, in which case the angular dimension may be placed on one of the related angles. In Fig. 3.1, if the draftsman desires to dimension angle A as 60 deg. but is unable to do so, he may dimension angle C as 60 deg. or may dimension angles B or D as 120 deg. (180 − 60 deg.).

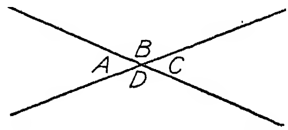


FIG. 3.1.—Angles formed by intersecting lines.

Exercise

3.3.1. If angle D in Fig. 3.1 = 42 deg., how many degrees are there in angles A, B, and C?

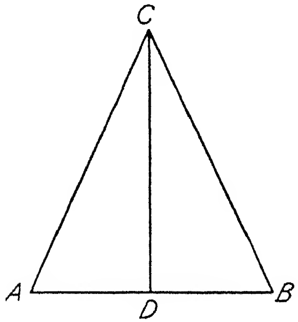


FIG. 3.2.—Isosceles triangle.

If in a triangle two angles are equal, the sides opposite those two angles are also equal; if two sides of a triangle are equal, the angles opposite those two sides are also equal. In Fig. 3.2, if the angle at A equals the angle at B, then the line BC is the same length as the line AC, or if the line BC is the same length as the line AC, then angle A equals angle B. A triangle in which two sides and two angles are equal is called an isosceles triangle. A perpendicular drawn from point C to line AB divides line AB

into two equal parts and also bisects the angle at C (divides angle C into two equal parts).

If a line passes through two parallel lines as shown in Fig. 3.3, the eight angles formed thereby are all definitely interrelated.

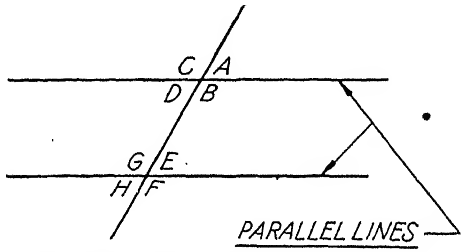


FIG. 3.3.—Angles formed by parallel lines.

The corresponding angles are equal: angle A equals angle E, angle B equals angle F, etc. Since the sum of angles A and B is known to equal 180 deg., the sum of angle A and angle F must also equal 180 deg. Also, angle A equals angle H, and angle D equals angle E, etc. The relation between the angles formed by parallel lines is used if space does not permit the placing of an angular dimension at the exact location desired on a drawing. The dimension may always be placed on an equal angle or on an angle which equals 180 deg. less the required angle. This latter angle is called the supplement of the given angle.

If a line intersects two other lines and the angles formed by the intersections are equal or supplementary, in accordance with the relations stated above, the lines are parallel. Thus, if angle G equals angle B, the lines are parallel; if angle $H = 69$ deg. and angle $C = 111$ deg., the lines are parallel, since the angles are supplementary $(69 + 111 = 180)$.

Exercises

3.3.2. Note the number of degrees in the other seven angles in Fig. 3.3 if (*a*) angle $D = 42$ deg., (*b*) angle $F = 121$ deg., (*c*) angle $A = 75$ deg.

3.3.3. Determine if the two lines in Fig. 3.3 are parallel if (*a*) angle $C = 86$ deg. and angle $F = 86$ deg., (*b*) angle $H = 59$ deg. and angle $B = 131$ deg., (*c*) angle $D = 28$ deg. and angle $F = 152$ deg., (*d*) angle $E = 91$ deg. and angle $C = 91$ deg. Lay out the above combinations of straight lines and angles, using the protractor and a triangle. Check their parallelness, using two triangles.

3.3.4. A parallelogram is a diamond-shaped figure composed of four intersecting straight lines, the opposite pairs of which are respectively parallel to each other. Prove that the diagonally opposite angles are equal. Check by laying out two different parallelograms, using two triangles to draw the parallel lines and measuring the diagonally opposite angles in each parallelogram with the protractor.

If a line is drawn perpendicular to one side of an angle and another line is drawn perpendicular to the other side of the angle, the two perpendicular lines intersect, forming angles that are

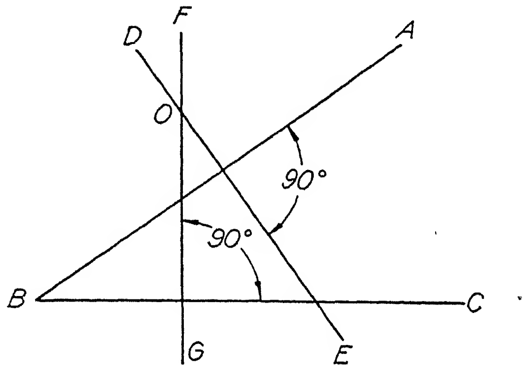


FIG. 3.4.—Angles formed by perpendicular lines.

either equal or supplementary to the first angle. In Fig. 3.4, angle ABC is the given angle. Line DE is perpendicular to line AB, line FG is perpendicular to line BC, and lines DE and FG intersect at point O. Angles DOF and GOE are equal to angle ABC; angles FOE and DOG are supplementary to angle ABC; *i.e.*, equal to 180 deg. less angle ABC.

Exercise

3.3.5. If angle ABC in Fig. 3.4 equals $36\frac{1}{2}$ deg., how many degrees will there be in the four angles of which O is the vertex?

The sum of the three interior angles of any triangle equals 180 deg. If two angles of a triangle are known to be 38 and 74 deg., the third angle $= 180 - (38 + 74) = 180 - 112 = 68$ deg. In a right triangle, since one angle is already known to be 90 deg., the sum of the other two angles must also equal 90 deg. (180 less 90 deg.). The interrelation of the angles of a triangle enables a draftsman to locate angular dimensions at the most convenient place on the drawing. In Fig. 3.5, if it is desired to

dimension the angle at A as 58 deg. but space does not permit, it will suffice equally well to dimension the angle at B as 32 deg.

Exercise

3.3.6. Lay out a triangle similar to that in Fig. 3.5, in which angle

$$B = 29 \text{ deg.}$$

Extend lines AB, BC, and AC, and note the number of degrees in all the angles which show the direction of line AB. How many such angles are found?

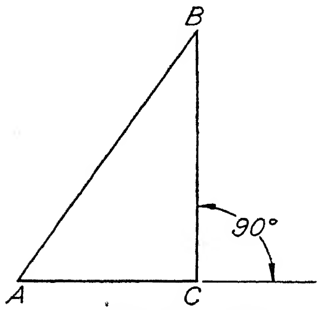


FIG. 3.5.—Relation of angles in a triangle.

The shape and size of a triangle are determined if the length of all three sides is known. The triangle is constructed by laying off the length of one of the sides on a given line. Using a compass radius equal to the length of the second side and the compass center located at one end of the first side, an arc is drawn. Using a compass radius equal to the length of the third side, and the compass center located at the other end of the first side, a second arc is drawn which will intersect the first arc. Lines are drawn connecting the intersection point with each end of the first side of the triangle, forming the required triangle.

Exercise

3.3.7. Construct a triangle the sides of which are 3, 4, and 5 in. Which two sides form a right angle?

The shape and size of a triangle are also determined if the length of two sides and the number of degrees in the angle between them is known. The angle is constructed, the length of one known side is laid off on one leg of the angle, and the length of the other known side is laid off on the other leg of the angle. These two end points are connected, forming the triangle. If any two angles and the length of one leg of a triangle are known, the shape and size of the triangle are determined. Knowing the value of any two angles of a triangle, the third angle may be found by subtracting the sum of the two known angles from 180 deg. The desired triangle is constructed by drawing a line the

length of which equals that of the known side of the triangle, laying off the two known angles at either end of the line, and extending the sides of these two angles until they intersect forming a triangle. Care must be exercised in selecting the proper angle to be used at each end of the given line.

Exercise

3.3.8. Construct the triangles sketched in Fig. 3.6 from the dimensions noted.

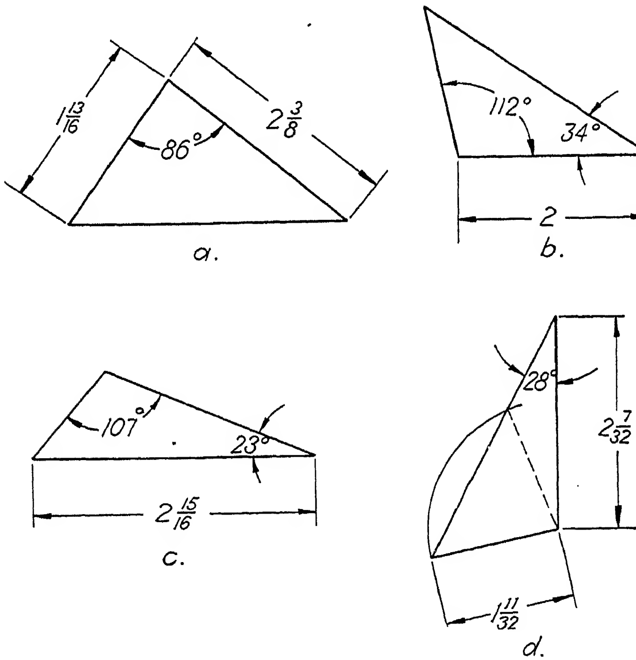


FIG. 3.6.—Constructing triangles.

An angle may be bisected as shown in Fig. 3.7. The compass is set at the largest radius convenient and, with its center exactly at point A, an arc is drawn, intersecting the sides of the angle at B and C. With any convenient radius (the radius just used to draw arc BC will usually be satisfactory) and using the intersection points of the arc and the sides of the angle as centers, two more arcs are drawn, intersecting at point D. The line AD then bisects the angle. This is a precision method of bisecting an angle the sides of which are much longer than the radius of

the protractor; ordinarily, short-sided angles are bisected by measuring the angle with a protractor and laying off half the angle by means of the protractor.

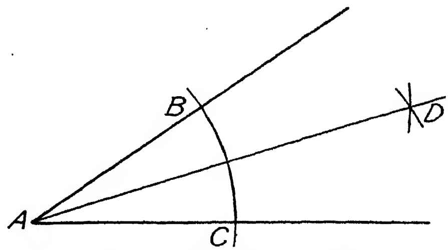


Fig. 3.7.—Bisecting an angle.

Exercise

3.3.9. Drawing 8, Angle—Bisecting an.—On the standard drawing form, draw a horizontal line 10 in. long, 1 in. above the bottom of the paper, and spaced approximately in the center between the sides of the paper. At the right-hand end of the line, draw a vertical line $8\frac{1}{8}$ in. long. Connect these two lines with a third line, forming a triangle.

a. Bisect the angle at the lower left-hand corner of the triangle using the protractor.

b. Bisect the same angle, using the compass method described above. Do the two bisecting lines coincide exactly?

c. Bisect the angle at the upper right-hand corner of the triangle, using the compass method.

Note.—Very sharp pencil and compass points should be used in making this construction, and care should be exercised to locate the compass point on the exact intersection of lines and arcs. Why is the compass method of bisecting an angle more precise than the protractor method?

It is often necessary to construct an angle equal to an angle already shown on a drawing or on another drawing. The usual procedure, when great accuracy is not required, is to measure the number of degrees in the given angle with the protractor and construct the required angle with the protractor, as shown in Fig. 1.26. If greater accuracy is desired, a line is drawn at a definite distance, as great as practicable, from the vertex of the angle, *e.g.*, 10 in., perpendicular to one side and intersecting the other side. The length of the perpendicular line is then measured. The required angle is obtained by laying off the definite distance from the vertex to the perpendicular line on the new base line, erecting the perpendicular line at that point to the same height as the perpendicular in the given angle, and con-

necting the vertex with the end of the perpendicular line. Thus, in Fig. 3.8, point *B* is located a given distance from point *A*, and the perpendicular distance *BC* is drawn and carefully measured. To construct an angle equal to angle *BAC* on line *DE* with the vertex at point *F*, a distance *FG* equal to distance *AB* is laid off. At point *G* a perpendicular is erected, the distance *GH* is laid off

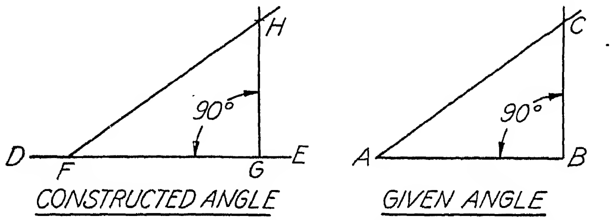


FIG. 3.8.—Constructing an angle equal to a given angle.

equal to the distance *BC*, and the points *H* and *F* are connected by a line. Angle *GFH* is then equal to angle *BAC*.

Exercise

3.3.10. Drawing 9, Angles—Construction of Equal.—On a standard drawing form draw a horizontal line 13 in. long, 1 in. above the title block, and spaced centrally on the drawing. With the left-hand end of the line as a vertex, draw an angle of 53 deg., using the protractor. At a distance of 6 in. from the left-hand end of the horizontal line, erect a perpendicular and extend the upper side of the angle to meet the perpendicular. Using a point 6½ in. from the left-hand end of the horizontal line as a vertex, construct a second angle equal to the first, and check with the protractor.

Perpendiculars to a line are usually drawn by using the 90-deg. angle of the triangle with a T square or with another triangle. For laying out very long perpendiculars that must be quite accurate, the geometric construction shown in Fig. 3.9 is used. On the line *AB* it is desired to erect a perpendicular at point *C*. With point *C* as a center and the largest radius possible, draw an arc intersecting line *AB* at *D* and *E*. With *D* and *E* as centers and using equal radii approximately half again the first radius, draw two arcs intersecting at *F*. Line *FC* will then be perpendicular to line *AB*. The accuracy of this con-

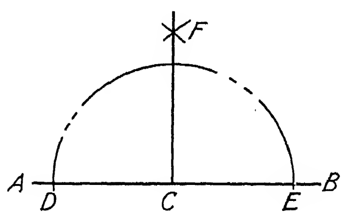


FIG. 3.9.—Constructing a perpendicular.

struction depends upon using large radii such as can be drawn with a beam compass, using a very fine compass point, locating the compass point accurately on the centers, and keeping points F and C as widely separated as possible.

By a similar construction, a perpendicular may be erected at the exact center of a line, as shown in Fig. 3.10. If a perpendicular through the mid-point of the line AB is desired, using a radius approximately equal to $\frac{2}{3}AB$ and point A as a center, draw the arc DE; using exactly the same radius and point B as the center, draw arc FG intersecting arc DE at points H and I. The line connecting points H and I is then perpendicular to line AB, and intersects it at the mid-point J so that distance AJ equals distance JB. The accuracy of this construction, like that of the previous one, depends upon using large radii, using a very fine compass point, locating the compass point accurately on the centers, and keeping points H and I as widely separated as possible.

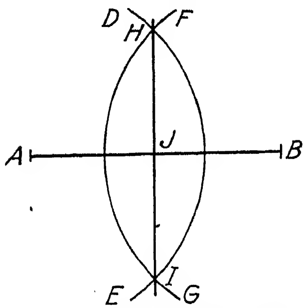


FIG. 3.10.—Constructing a perpendicular bisector.

Exercise

3.3.11. Draw a vertical line 5 in. long and construct the perpendicular which passes through the mid-point of the vertical line.

A line may be divided into a given number of equal lengths by using a pair of dividers (a compass in which the lead point is replaced by a steel point). The gap between the points is adjusted to approximately the length of the space desired, and one point of the dividers is placed on one end of the line. The other point is pricked into the paper on the line and, while held there, the first point is lifted and the dividers are rotated until the first point can be pricked into the paper ahead of the second point. This process is repeated, or the dividers are "walked" along the line, until the desired number of spaces has been stepped off. The end point of the last space will fall either short or long of the end of the required line. The dividers are readjusted to make the space longer or shorter, as required, and the line is again stepped off. This process of adjusting the dividers

and stepping off the line is repeated until the dividers are set to exactly the right length.

A much faster geometric method of dividing a line into an equal number of segments is shown in Fig. 3.11. If a line AB, 4

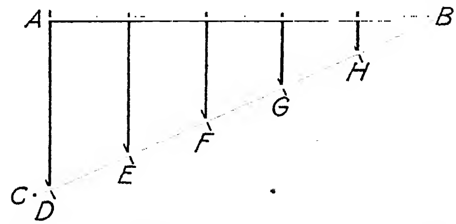


FIG. 3.11.—Dividing a line into equal segments.

in. long, is to be divided into five equal segments, line BC is drawn at any convenient angle and, using a 12-in. rule, five equal segments are laid out from point B. In this particular case, the segments along BC are made $\frac{7}{8}$ in. long, the last one falling at point D. The line AD is drawn, and, using the triangles, four lines are drawn parallel to line AD and passing through points E, F, G, and H intersecting line AB. These five parallel lines divide line AB into five equal segments. This construction may be accomplished very rapidly, since it does not involve a trial and error method as does the procedure with the dividers. The construction lines should be drawn in very lightly with a sharp pointed 4H pencil so that the construction lines BC, AD, and the lines parallel to AD, may be erased after completing the construction.

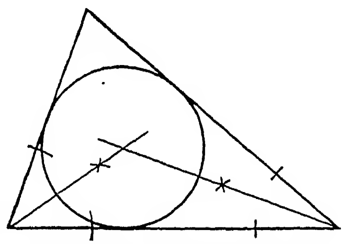


FIG. 3.12.—Inscribing a circle in a triangle.

Exercise

3.3.12. Draw a line $5\frac{1}{2}$ in. long, and divide it into 13 equal spaces. Use the divider method, then the triangle and ruler method. Which is faster?

3.4. Circles.—In order to construct a circle which is tangent to all three sides of a triangle, two angles of the triangle are bisected, the compass point is located at the intersection of the two bisectors, and the radius is adjusted so that the arc is tangent to one side of the triangle. The remainder of the circle is drawn;

if the construction has been accurate, the circle will be found to be tangent to the other two sides of the triangle, as shown in Fig. 3.12.

Exercises

3.4.1. Draw a triangle the sides of which are 3, 4, and 5 in. long, respectively. Construct the circle that is tangent to the three sides of the triangle. What is the radius of the circle?

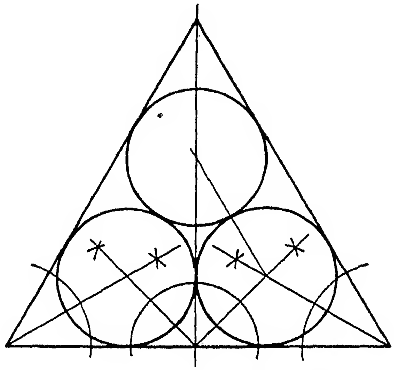


FIG. 3.13.—Equilateral triangle with three tangent inscribed circles.

3.4.2. Draw a triangle, each side of which is 4 in. long. Draw a line from one vertex perpendicular to the opposite side, and construct two circles tangent to this line and the two adjoining sides of the triangle. Note that the radii of the two circles are equal. With the same radius, draw a third circle within the triangle tangent to the first two circles. If the construction has been accurately made, this third circle will also be tangent to two sides of the triangle (see Fig. 3.13).

The construction of a circle passing through the three vertices of a triangle is shown in Fig. 3.14. In triangle ABC, line DE and FG are erected perpendicular to lines AC and BC at the midpoints of these lines. Using the intersection point H as a center and a radius equal to HA, the required circle is drawn.

Exercise

3.4.3. Draw a triangle whose sides are 2, $2\frac{1}{2}$, and $3\frac{3}{4}$ in., respectively. Construct a circle which passes through the vertices of this triangle.

If a radius is drawn perpendicular to a chord, it divides the chord into two equal lines, and the arc subtended by the chord into two equal arcs (see Fig. 3.15). This principle is used in reverse when constructing a circle that is required to pass through three points (see Fig. 3.15). To draw a circle through points

A, *B*, and *C*, perpendiculars are drawn through the mid-points of lines *AB* and *BC* which intersect at point *D*. With point *D* as a center and *AD* as a radius, the required circle is then drawn. If the center of a circle or an arc is not known, it may be found

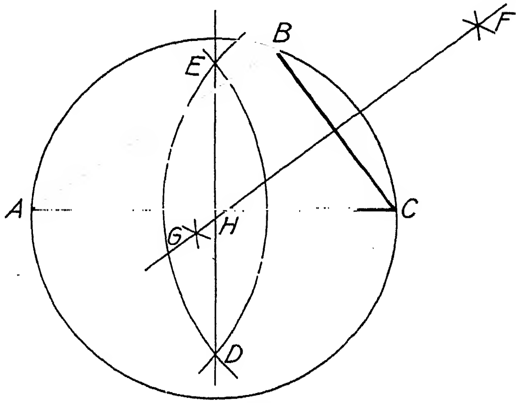


FIG. 3.14.—Constructing a circle passing through the vertices of a triangle.

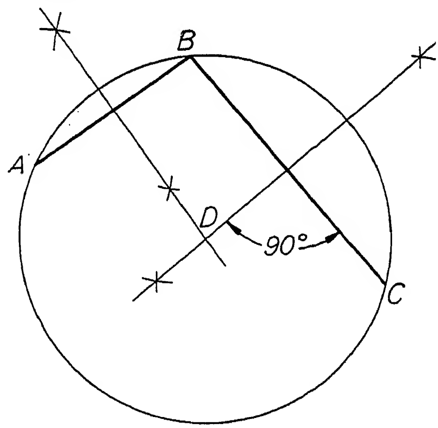


FIG. 3.15.—Constructing a circle passing through three points.

by drawing any two chords and by erecting perpendiculars at the centers of the chords. These two perpendiculars will intersect at the center of the circle.

Exercise

3.4.4. Draw a horizontal line 2 in. long. At the right-hand end of the line draw a line $1\frac{1}{2}$ in. long, making a 60-deg. angle with the first line. Construct a circle passing through both ends of both lines.

If a tangent is drawn to a circle, a radius drawn to the point of tangency is perpendicular to the tangent. If a radius is perpendicular to the tangent of a circle, the radius passes through the point of tangency. If a line is perpendicular to a tangent at the point of tangency, the line passes through the center of the circle. If a line is drawn perpendicular to a radius at the point where the radius intersects the circumference of the circle, the line is tangent to the circle. The above four statements are different ways of describing the same relations among circles, radii, and tangents (see Fig. 3.16).

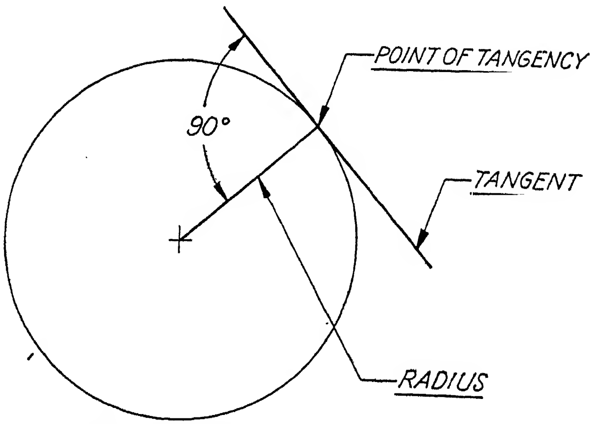


FIG. 3.16.—Relation of radii and tangents of a circle.

The point of tangency is important in drafting, for it indicates where a curved surface stops and a tangent straight surface begins. The point of tangency may be located exactly by placing the hypotenuse of a 45-deg. triangle on the tangent and placing another triangle firmly against one leg of the first triangle. The first triangle is rotated until the other perpendicular leg lies against the second triangle so that the hypotenuse makes a 90-deg. angle with its former position and passes through the center of the circle (see Fig. 3.17). If it is required to draw a tangent to a circle at a given point, a radius is drawn to that point, and a line perpendicular to the radius is drawn through the given point (see Fig. 3.18). The above procedures apply equally to arcs and to complete circles.

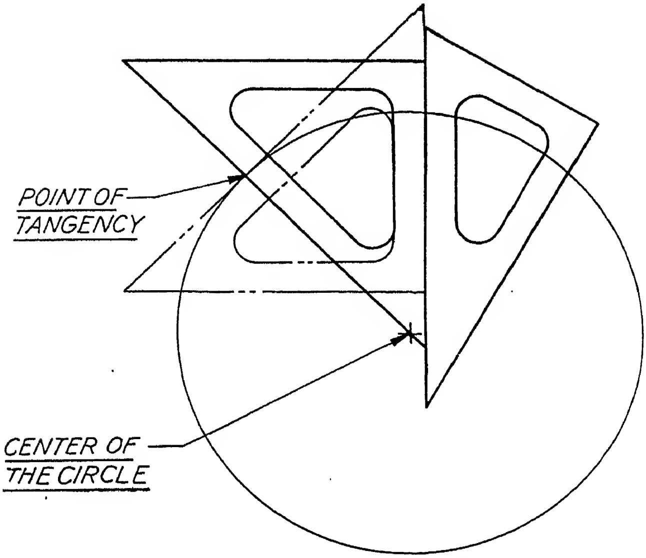


FIG. 3.17.—Locating the point of tangency.

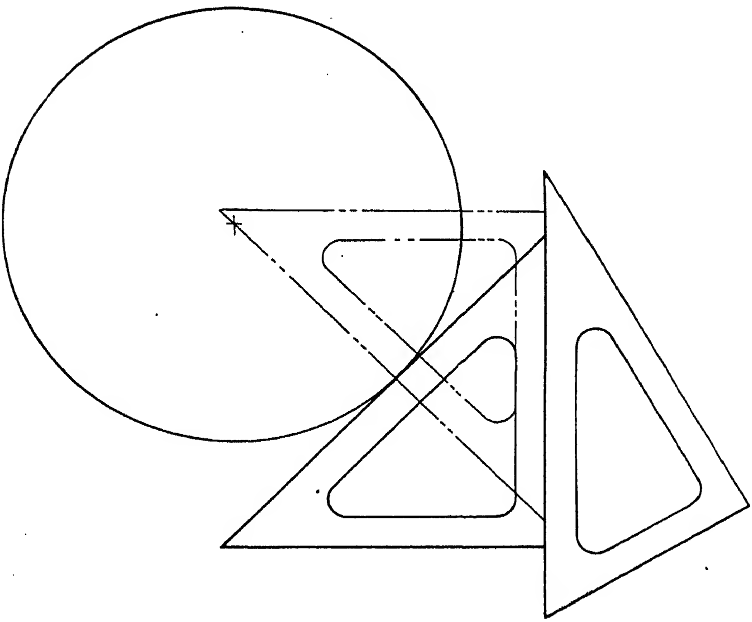


FIG. 3.18.—Constructing a tangent at a given point on a circle.

Exercises

3.4.5. Draw a 2-in.-radius circle and draw any three tangents. Locate the points of tangency, draw the radii to these points of tangency, draw another 2-in.-radius circle, and locate three points on its circumference at random. Construct the tangents through these points.

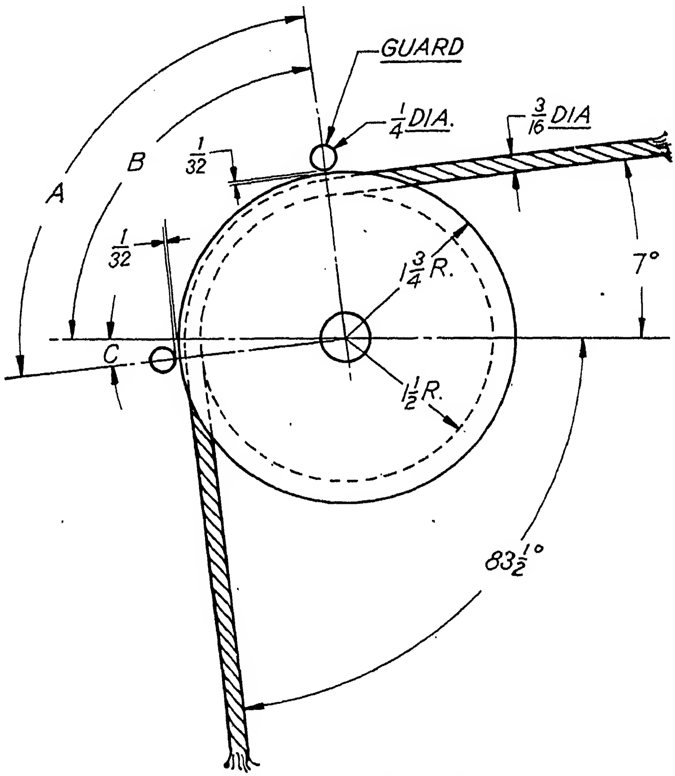


FIG. 3.19.—Cable pulley guards.

3.4.6. When a cable passes over a pulley, guards are placed just outside the pulley and usually at the point of tangency to prevent the cable from "jumping the track" should the cable slacken suddenly. Lay out the pulley and the cables shown in Fig. 3.19 to accurate scale. Draw the radii through the points of tangency of the cable to the inner dotted line of the pulley, representing the bottom of the slot. Extend these radii and draw the cable guard pins. Knowing that the radii are perpendicular to the cables, calculate the angles between the guards and the horizontal center line. Check these calculations by actual measurements with a protractor.

3.5. Problems in Location.—It is often important to know the location of all the points that will satisfy a certain set of conditions, such as the location of the centers of all the ½-in.-radius circles tangent to a given line. The center of any such circle will be a point ½ in. away from the given line on either side. If a number of points are located, they will all lie on one or the other of the two lines, parallel to the first line and ½ in. on either

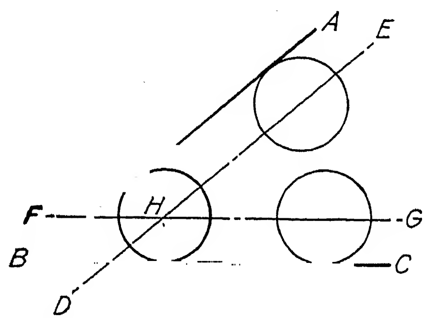


FIG. 3.20.—Constructing a circle tangent to two intersecting lines.

side of it. These parallel lines are then the location (or locus) of the centers of all ½-in.-radius circles tangent to the given line. This idea may be applied to the construction of an arc of given radius which is tangent to two intersecting lines. The centers of all ¼-in.-radius circles tangent to the line *AB* in Fig. 3.20 lie on line *DE*, ¼ in. away from line *AB* and parallel to it. The centers of all such circles tangent to line *BC* lie on line *FG*, ¼ in. away from line *BC* and parallel to it. A ¼-in.-radius circle tangent to both lines *AB* and *BC* must have its center both on line *DE* and on line *FG* and, therefore, must be at point *H*, since this is the only point common to both lines.

Exercise

3.5.1. Draw a 33-deg. angle and construct a circle of ⅝ in. radius tangent to both sides of the angle.

The center of a circle of radius R_1 tangent to a second circle of radius R_2 is always a distance R_1 outside or inside the second circle, as shown in Fig. 3.21. The location of the centers of *all* circles of radius R_1 and tangent to a second circle of radius R_2 will lie on two new circles, the radii of which are equal to $R_2 + R_1$ or $R_2 - R_1$. If the radius of the given circle is 1 in. and

if the radius of the tangent circle is ¾ in., the centers of all the tangent circles lie on two new circles with radii of 1 − ¾ or ¼ in. and 1 + ¾ or 1¾ in. With the center any place on the circumference of either the ¼-in. or the 1¾-in. circles and using a radius of ¾ in., any circle drawn will be tangent to the given 1-in.-radius circle.

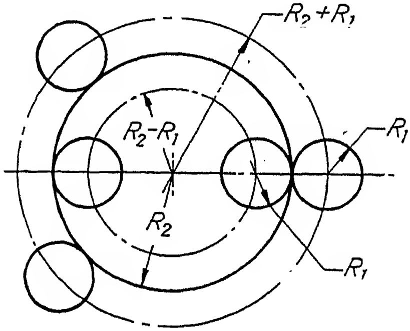


FIG. 3.21.—Tangent circles.

Exercise

3.5.2. Draw a 2³⁄₁₆-in.-radius circle, and draw the circles which locate the centers of all ¹⁹⁄₃₂-in.-radius circles tangent to the first circle. Draw eight such circles of ¹⁹⁄₃₂ in. radius tangent to the larger circle. Locate their centers on the vertical and horizontal lines passing through the center of the 2³⁄₁₆-in.-radius circle.

In general, to draw a circle tangent to two given lines, either straight or curved, construct a line containing the centers of all the required circles that would be tangent to one of the given lines, and construct another line containing the centers of all the required circles tangent to the other given line. The point where the two construction lines intersect is the center of the given circle tangent to both the given lines.

The procedure for drawing a circle of ⅜ in. radius, tangent to both a 1³⁄₁₆-in.-radius circle and a line 1¹¹⁄₁₆ in. below the center of the given circle is shown in Fig. 3.22. The location of the radius centers of all the ⅜-in.-radius circles tangent to the given circle is first drawn as two circles concentric with the given circle. The location of the centers of all ⅜-in.-radius circles tangent to the given straight line is next drawn as two parallel lines ⅜ in. above and below the given line. It may be observed that the lower location line and the inner location circle do not intersect.

The outer location circle and the upper location line do intersect at point A. Point A, therefore, is the center of the required $\frac{3}{8}$-in.-radius circle, for it lies on the outer location circle so that the $\frac{3}{8}$-in.-radius circle will be tangent to the given circle, and it

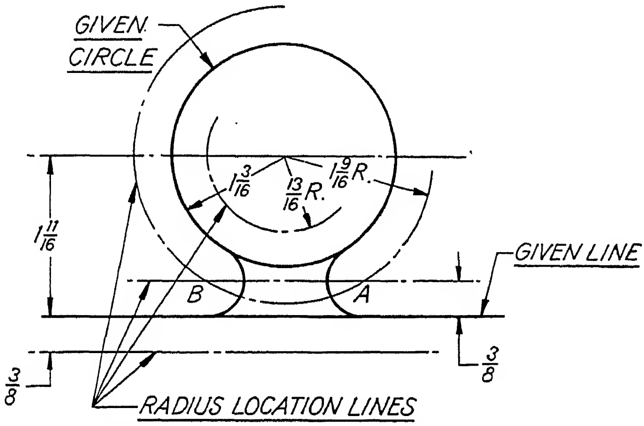


FIG. 3.22.—Arcs tangent to a circle and a straight line.

also lies on the upper location line so that it will be tangent to the given line. The outer location circle and upper location line intersect again at point B, from which center a second $\frac{3}{8}$-in.-radius circle may be drawn tangent to both the given circle and the given line.

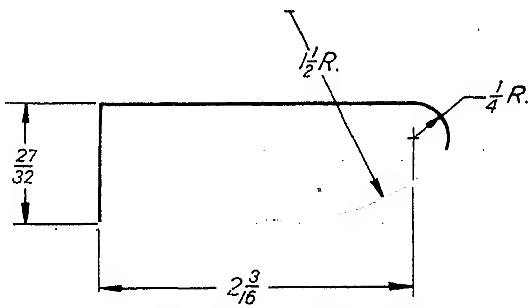


FIG. 3.23.—Filler—pulley bracket.

Exercises

3.5.3. Draw a $1\frac{11}{16}$-in.-radius circle and a straight line $1\frac{3}{32}$ in. below its center. Draw all $\frac{7}{32}$-in.-radius circles that are tangent to the given line and the given circle. How many such circles may be drawn?

3.5.4. Draw a $\frac{15}{16}$-in.-radius circle and a $1\frac{7}{32}$-in.-radius circle, with $2\frac{5}{16}$ in. between centers. Draw all the $\frac{3}{4}$-in.-radius circles that will be tangent to both given circles.

3.5.5. Draw the object shown in Fig. 3.23. It should be noted that the $1\frac{1}{2}$-in.-radius center is not located by dimensions, since the $\frac{1}{4}$ in. radius and the bottom straight line determine its center.

3.6. Ellipses.—An ellipse is an oval-shaped figure. When the end of a piece of rubber tubing is squeezed, the end appears as a flattened-out circle, or oval shape, and closely resembles an ellipse. If a round coin is held flat directly beneath a light, it casts a circular shadow. If, however, it is held at an angle, the shadow is elliptical in shape.

Ellipses are encountered more or less frequently in aircraft drawing. The tips of airplane wings and horizontal and vertical tail surfaces are often elliptical in shape. The holes cut in flat surfaces, such as firewalls, wings, and fuselages, to clear a round pipe passing through these surfaces at an oblique angle (an angle which is greater or less than 90 deg.) is elliptical in shape. For appearance, convenience, and utility, elliptical shapes may be used for cabin windows, entrance doors, and fuselage cross sections. Circular surfaces viewed from an oblique angle appear elliptical on a drawing. Ellipses have the advantage of being capable of exact reproduction at any plant or factory without requiring cumbersome loft boards upon which the desired curve is drawn or complicated tables of offsets to locate the points which determine the curve. This duplication may be accomplished if two simple dimensions are known: the length of the major axis and the length of the minor axis. An ellipse will be exactly the same size and shape as any other ellipse with the same major and minor axes.

The major axis is the longest straight line that can be drawn from one side of the ellipse to the other. The center of the ellipse is the mid-point of the major axis. The minor axis is the shortest straight line that can be drawn from one side of the ellipse to the other, passing through the center; it is at 90 deg. to the major axis. The minor semiaxis is the distance along the minor axis from the center to the side of the ellipse, or half the length of the minor axis. The major semiaxis is the distance along the major axis from the center to the side of the ellipse and is half the major axis. An ellipse and the terms relating to it are illustrated in Fig. 3.24.

There are many methods of laying out ellipses with more or less accuracy. There are instruments available which will actually construct an ellipse, given the major and minor semi-axes. The simplest and most practical method of laying out an ellipse is outlined in the following steps (see Fig. 3.25):

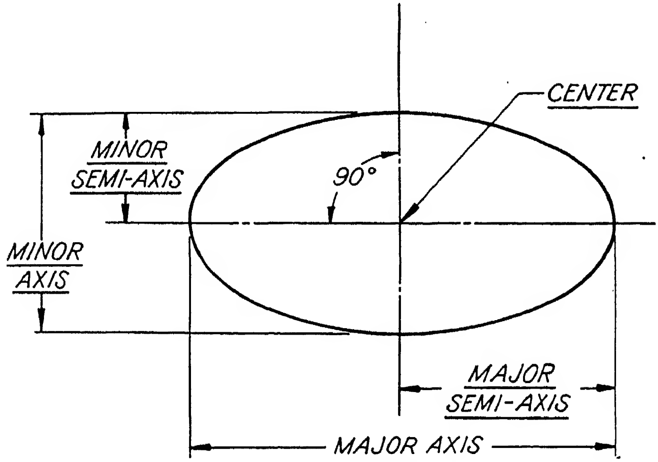


FIG. 3.24.—An ellipse.

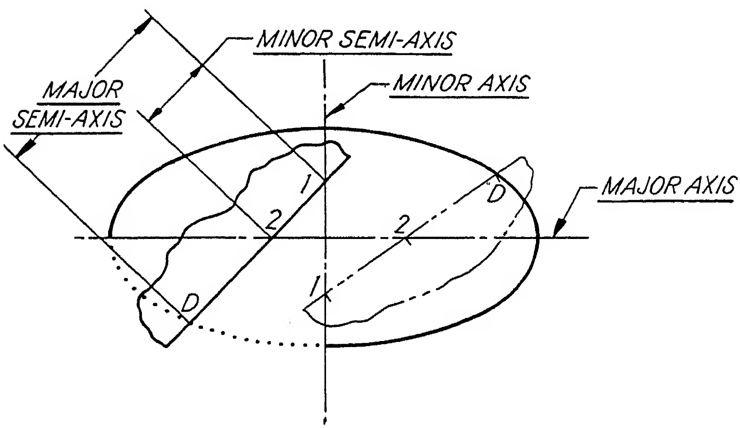


FIG. 3.25.—Constructing an ellipse.

1. Lay out two lines at right angles to each other on the drawing and lay off the major and minor axes on these lines, using as a center the intersection of the perpendicular lines.

2. Lay a piece of paper with its straight edge on the major axis, and make a fine mark on the paper exactly at one end of the major axis and another fine mark on the paper exactly at the center of the ellipse. Label the first point *D* (the drawing point) and the second point 1.

3. Move the paper so that its straight edge lies on the minor axis with point *D* exactly at one end of the minor axis and point 1 near the center. Make a fine mark on the paper at the exact center of the ellipse and label this point 2.

4. Keeping point 1 on the minor axis and point 2 on the major axis, rotate the paper, making dots on the drawing where point *D* falls. These dots may be spaced as closely as necessary to draw a smooth curve; the closer the dots are spaced, the more accurate the ellipse will be.

5. Connect the points, using an irregular curve to get a smoothly faired line.

This procedure has the particular advantage that no construction lines are required; upon the completion of the construction, no lines appear except the ellipse itself and the major and minor axes.

Ellipses may be approximated or "faked" if they are small or their shape is not important. The first step is to lay out the major and minor axes; then two small arcs are drawn, using a radius approximately one-third the minor axis, with the center on the major axis and the arcs touching the ends of the major axis. By using an irregular curve, two lines may be drawn through the ends of the minor axis and tangent to the two arcs. The two arcs may also be connected by drawing an arc or a circle of sufficiently large radius so that the arc will pass through the end of the minor axis and be tangent to the two arcs.

Very tiny ellipses may be drawn freehand by first laying out the major and the minor axes and then carefully drawing a curve through these points. Rivet heads, when seen at an angle, appear as ellipses and may be drawn freehand as described above.

Exercises

3.6.1. Construct an exact ellipse the major and minor axes of which are 5⅜ and 3¼ in., respectively. Using circular arcs, draw an approximate ellipse with major and minor axes of 1¼ and ¾ in. Check the shape of the approximate ellipse by laying out the points for an exact ellipse on the same axes. Draw freehand ellipses the major and minor axes of which are (*a*)

$\frac{3}{8}$ in. and $\frac{1}{4}$ in., (*b*) $\frac{1}{2}$ in. and $\frac{3}{16}$ in., (*c*) $\frac{1}{4}$ in. and $\frac{3}{16}$ in., (*d*) $\frac{13}{32}$ in. and $\frac{5}{32}$ in. Check one of these freehand ellipses, using exact points.

3.6.2. Drawing 10, Cutout—Ventilating Duct.—On a standard drawing form draw the hole which must be cut in a thin flat plate to permit a 4-in.-

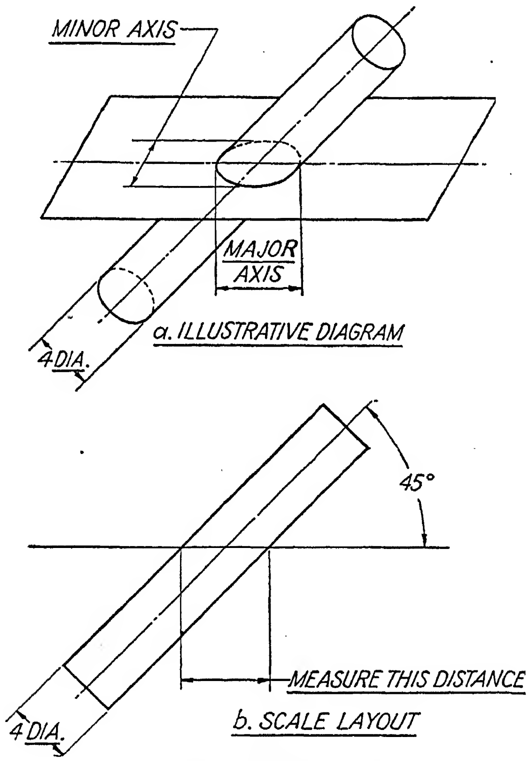


FIG. 3.26.—Elliptical cutout.

diameter pipe to pass through if the axis of the pipe is 45 deg. to the plane of the plate.

HINT.—The hole is an ellipse the minor axis of which is the diameter of the pipe; the major axis is equal to the distance across the pipe at a 45-deg. angle (see Fig. 3.26).

3.7. Problems.

3.7.1. Determine by inspection the number of degrees in the angles identified by letters in Fig. 3.27. Lay out the figures shown to scale, and check the number of degrees previously determined in each lettered angle by measuring it with a protractor.

3.7.2. Lay out the gusset shown in Fig. 3.28. Measure the number of degrees in the three angles formed by the intersection of the sides of the

gusset or their extensions. Extend the sides, and draw angular dimensions where most convenient to define these angles.

3.7.3. A polygon is a figure composed of three or more straight sides. Since the sum of the interior angles of any polygon consists of the sum of the

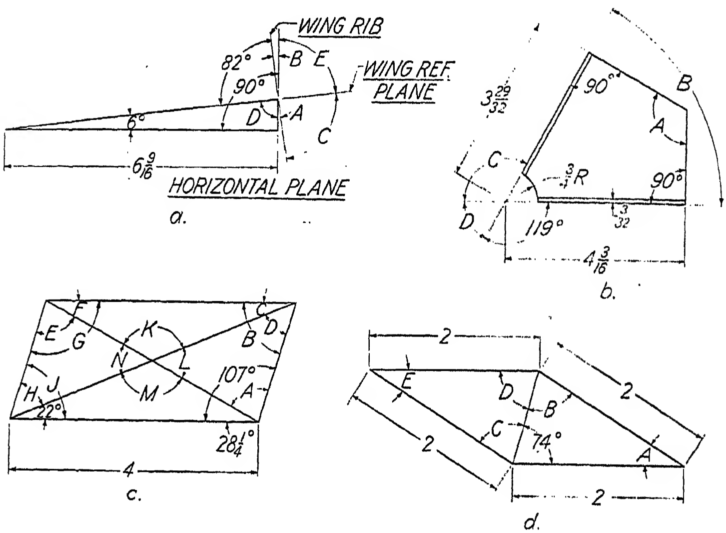


FIG. 3.27.—Determining angles.

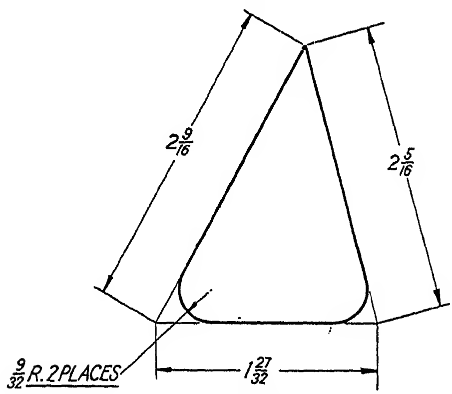


FIG. 3.28.—Gusset.

interior angles of a fixed number of triangles (see Fig. 3.29), the sum of the interior angles of any polygon is determined by the number of sides of the polygon. What is the sum of the interior angles of (*a*) a square, (*b*) a five-sided figure (pentagon), (*c*) a six-sided figure (hexagon), (*d*) an eight-sided figure (octagon)?

A regular polygon is a figure with all sides equal in length and all angles equal. How many degrees are there in one interior angle of (*a*) an equilateral triangle, (*b*) a square, (*c*) a regular pentagon, (*d*) a regular hexagon, (*e*) a regular octagon?

3.7.4. Aircraft nuts and boltheads are regular hexagons, with one side roughly equal to the diameter of the bolt. Draw hexagons of the same size as heads of bolts of the following diameters: ¼ in., 7⁄16 in., ½ in., 9⁄16 in., ¾ in.

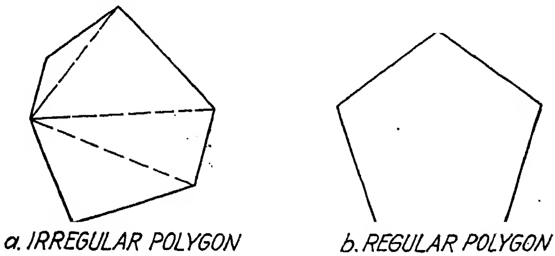


FIG. 3.29.—Polygons.

NOTE.—In the accurate representation of boltheads on a drawing, the distance across the flats—*i.e.*, the distance between the parallel sides of the boltheads—is determined from tables. A circle the diameter of which equals the distance across the flats is drawn about the center of the bolt, and the flat sides of the heads are drawn tangent to the circle, using the triangle that makes the correct angle. What is the correct angle (see Fig. 3.30)?

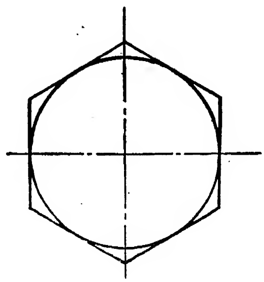


FIG. 3.30.—Drawing boltheads.

3.7.5. The center of a circle inscribed in a regular polygon may be located by finding the intersection of the perpendicular bisectors of two adjacent sides. Inscribe circles in the hexagons drawn in Problem 3.7.4.

3.7.6. If a taut cable passes over a pulley, it exerts a force on the pulley in the direction of the bisector of the angle made by the two cables. Lay out the cable and pulley shown in Fig. 3.31, and bisect the angle. Calculate the number of degrees in angles *A*, *B*, *C*, and *D*, and check these values, using the protractor.

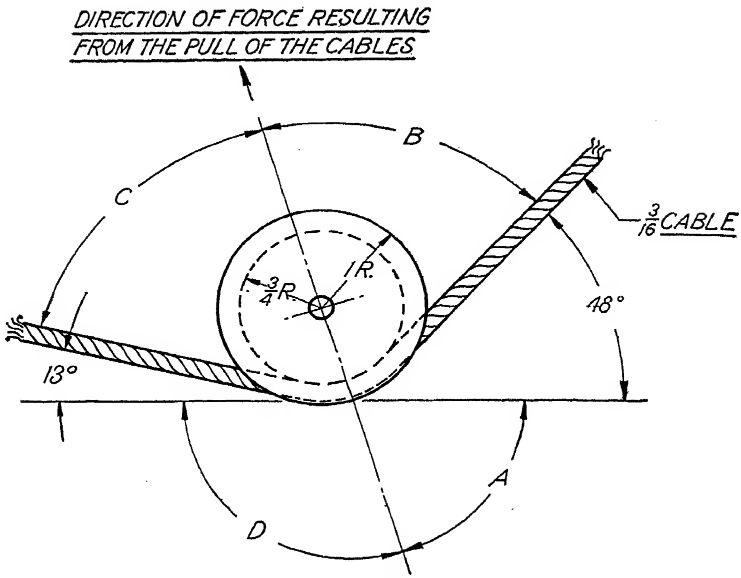


FIG. 3.31.—Pulley and cable.

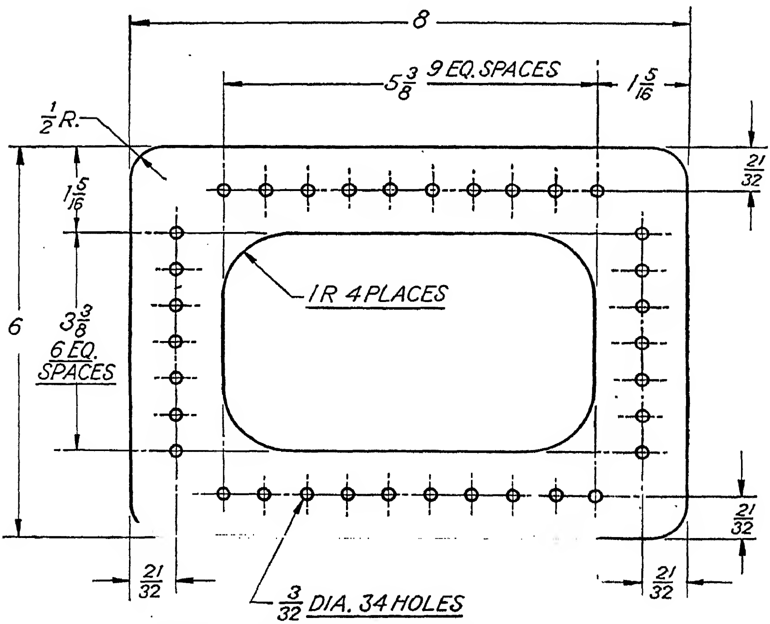


FIG. 3.32.—Doubler—outboard wing access door.

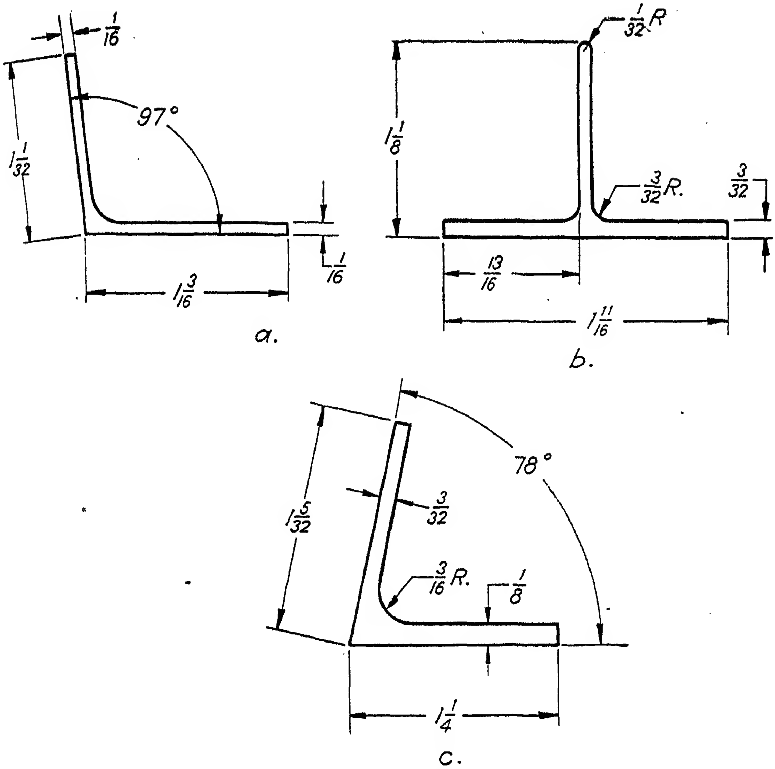


FIG. 3.33.—Extrusions.

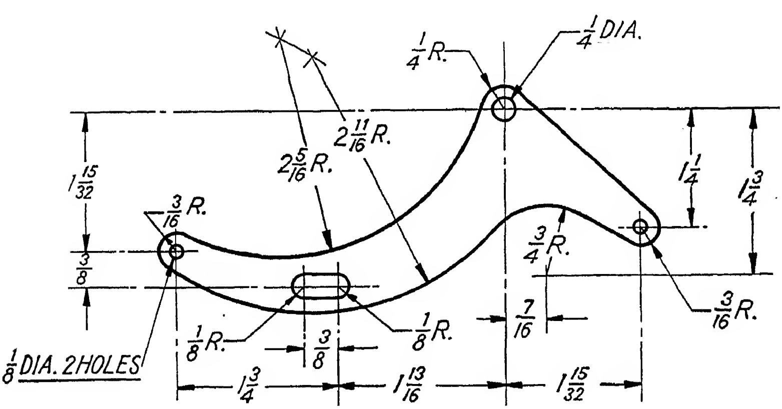


FIG. 3.34.—Lever—engine starter control.

3.7.7. Draw a horizontal line 10 in. long. At the left-hand end of the line construct an angle of 46½ deg., using a protractor. Erect a perpendicular at the right-hand end of the line. On another horizontal line duplicate this angle, using the same length of horizontal and vertical lines.

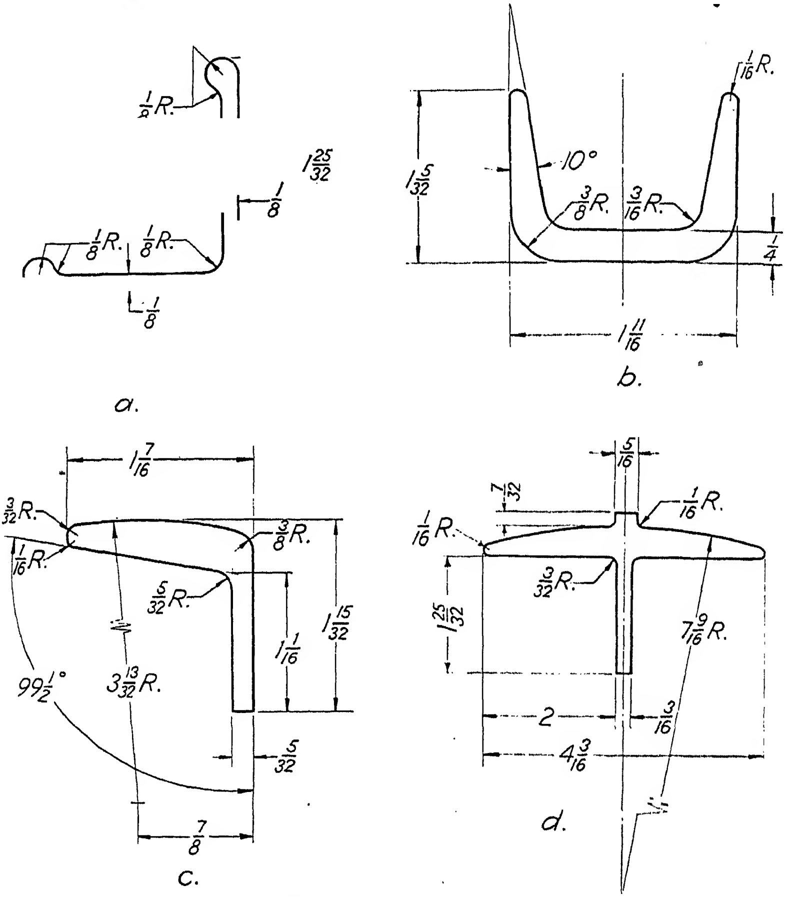


FIG. 3.35.—Extrusions—special.

3.7.8. On an 11½ in. long line, construct a perpendicular 5⅞ in. from the left-hand end of the line.

3.7.9. Drawing 11, Doubler—Outboard Wing Access Door.—Lay out the doubler shown in Fig. 3.32 on a standard drawing form.

3.7.10. Extrusions are lengths of metal, usually aluminum alloy or magnesium alloy, of a constant cross-sectional shape. They are produced by forcing the hot metal through a die in which is cut a hole of the exact shape of the desired extrusion. The cost of the die is based upon the

diameter of the smallest circle that will contain the extrusion shape. Lay out the extrusions shown in Fig. 3.33, and draw the circumscribed circles.

HINT.—Circumscribe circles about the triangles the vertices of which are the three outermost points of the extrusions.

3.7.11. Locate the points of tangency of the cable to the pulley shown in Fig. 3.31.

3.7.12. Drawing 12, Lever—Engine Starter Control.—Lay out the lever shown in Fig. 3.34 on a standard drawing form. Show all dimensions.

3.7.13. Drawing 13, Extrusions—Special.—Divide a standard drawing form into four equal rectangles, and lay out and dimension the extrusions shown in Fig. 3.35.

3.7.14. Drawing 14, Glass—Main Cabin Window.—On a standard drawing form lay out an ellipse of $6\frac{3}{32}$ in. minor axis and $8\frac{29}{32}$ in. major axis. Note "Half Size" just above the title block; note "True Ellipse" adjacent to the outside of the ellipse, and connect this note to the ellipse with a leader line and an arrow. Dimension the major axis $17\frac{13}{16}$ and the minor axis $12\frac{3}{16}$.

CHAPTER 4

ORTHOGRAPHIC PROJECTION

4.1. Introduction.—Drafting instruments were discussed in Chap. 1, and skill and facility in their use were developed so that these instrumênts could be used in making a drawing. Chapter 2 was devoted to the development of clear and rapid lettering so that special instructions might be added to the pictures produced with the instruments. In Chap. 3, special techniques were introduced to save time and to enable the draftsman to make a better picture. These three chapters were meant as a preparation for orthographic projection. Orthographic projection consists of a series of flat views which, taken together, define an object that has depth. It is similar to a series of flat sheets of paper which, when properly assembled, form a solid-looking object. The skills developed in the first three chapters will be constantly used and, when necessary to refresh the memory, information therein should be referred to.

4.2. The Idea of a View.—A view in orthographic projection is a diagram of a physical object as seen from a single direction.

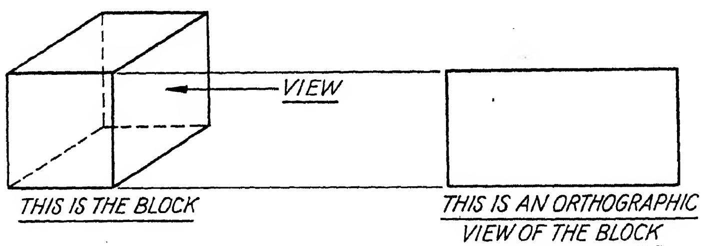


FIG. 4.1.—A block.

The problems and exercises in Chaps. 1 and 3 consisted principally of single views of objects. In Fig. 4.1, the orthographic view on the right is a diagram of the block on the left, as it would appear if the observer looked at the block in the direction of the arrow and drew a picture of what he saw.

Exercise

4.2.1. Draw a view of the block in Fig. 4.1 as seen from the top and another view as seen from the front.

4.3. Visible Outline.—These diagrams or views are composed of four different kinds of lines, each of which has a particular significance. The first type is called a "visible outline"; it is always a wide black line and shows the outline of a part. The

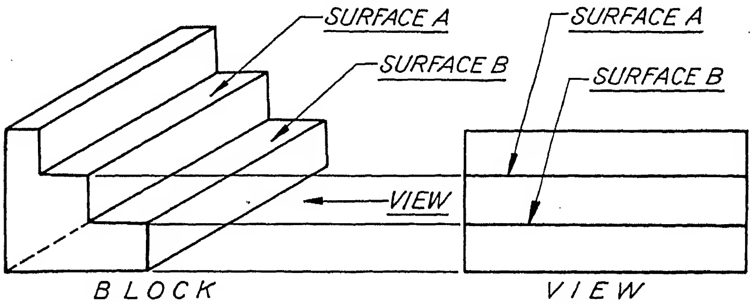


FIG. 4.2.—Surfaces on edge.

four straight lines forming the view in Fig. 4.1 are visible outlines. Visible outlines are also used to represent flat surfaces seen on edge in the view. Thus, in Fig. 4.2 surfaces *A* and *B* of

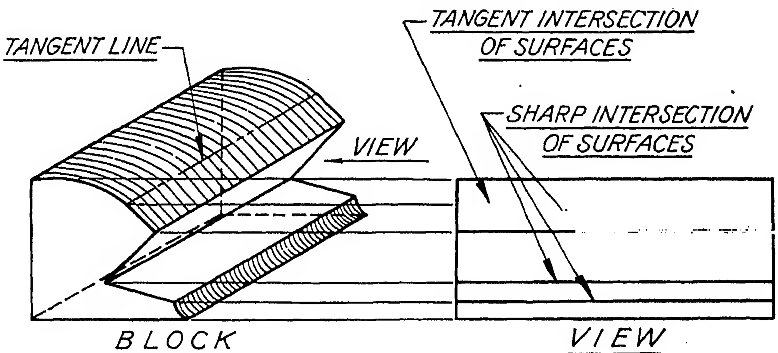


FIG. 4.3.—Sharp and faired intersections.

the block appear as two straight visible outlines in the view. Also, the top and bottom visible outlines of the view represent the top and bottom surfaces of the block. Are there any other visible outlines in Fig. 4.2 which represent surfaces seen on edge?

If two straight or curved surfaces of a block meet at a sharp angle, *i.e.*, they do not fair smoothly into each other, their intersection appears in the view as a visible outline. If the two surfaces fair smoothly into each other, the intersection (tangent line) does not appear as a visible outline. In Fig. 4.3, the view shows three visible outlines within the outline of the block, which represent sharp intersections of surfaces. The tangent line

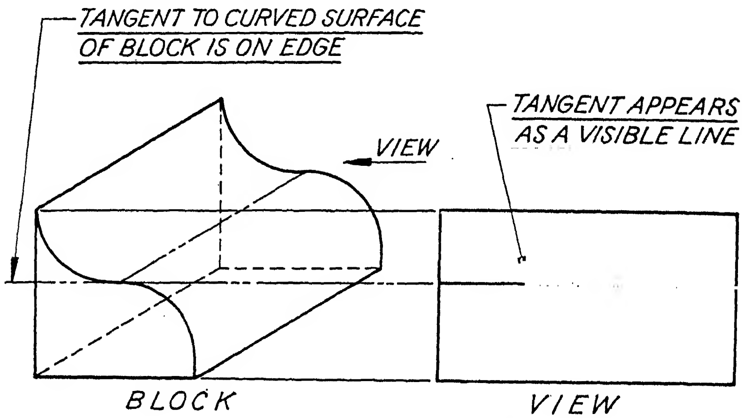


FIG. 4.4.—Curved surface on edge.

between the top curved surface and the adjacent straight surface does not appear as a visible outline in the view, since there is no sharp break in the surface of the part at the tangent line.

If a smoothly curved surface winds around until it is on edge even at a single place (*i.e.*, the tangent is on edge), that place will appear as a visible outline (see Fig. 4.4).

Exercise

4.3.1. Draw views as indicated for the blocks shown in Fig. 4.5. The scale of the views is not important, but lengths of lines may be approximated by measuring the corresponding lines in the sketches.[1]

4.4. Invisible Outline.—To convey more information on a view than that which could be seen with the eye, lines hidden inside or in the back of the object are also shown on a drawing.

[1] The sketches of the blocks in Figs. 4.1 to 4.5 are called "isometric" drawings and are quite useful in drafting work to give an idea of the "solid" appearance of a part—since the orthographic views indicate its flat appearance only.

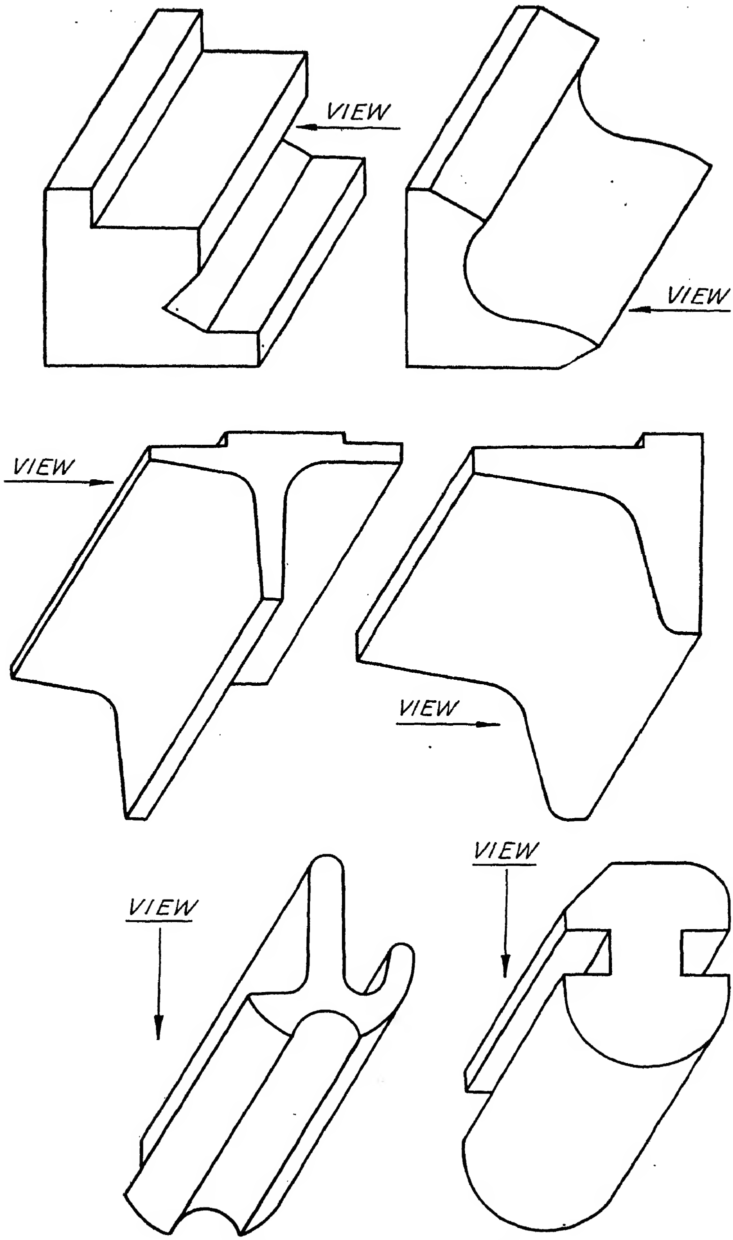


FIG. 4.5.—Exercise in views.

To distinguish these hidden lines from ordinary or visible outlines, a second kind of line, the "invisible outline," is used. It is

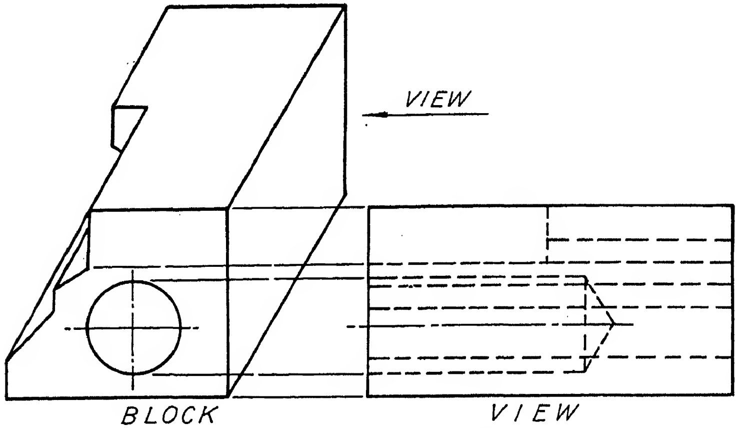


FIG. 4.6.—Invisible outlines.

a series of short dashes, each one approximately 3/16 in. long and separated by a space that is much shorter than the dash (approxi-

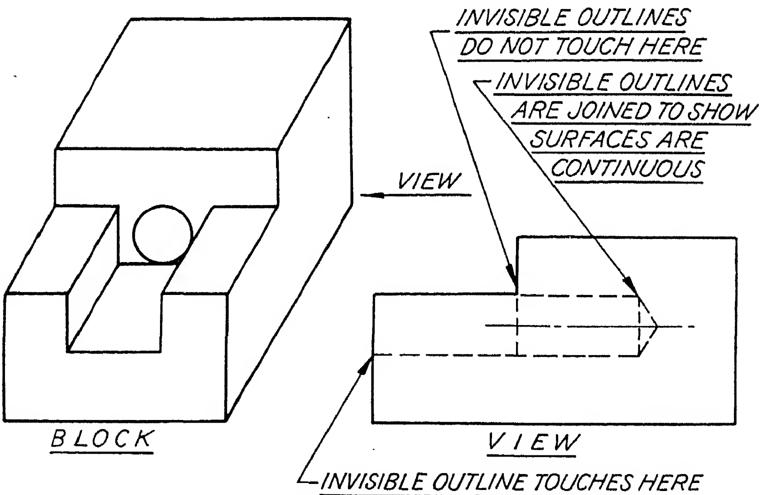


FIG. 4.7.—Starting and ending invisible outlines.

mately one-fourth as long as the dash), thus — — — — — — — —. The invisible outline is only slightly narrower than the visible outline, and shows hidden edges, surfaces, intersections, and

curved surfaces perpendicular to the paper in the same way as the visible outline shows visible edges, surfaces, etc.

In Fig. 4.6, the hole and the notches in the block are shown in the view by a series of dotted lines just as though X-ray vision enabled the observer to see right through the block. The last dash of an invisible outline that ends on a visible outline should touch the visible outline unless the same surface continues through as a visible surface. Invisible outlines that end on other invisible outlines should always connect (see Fig. 4.7). The

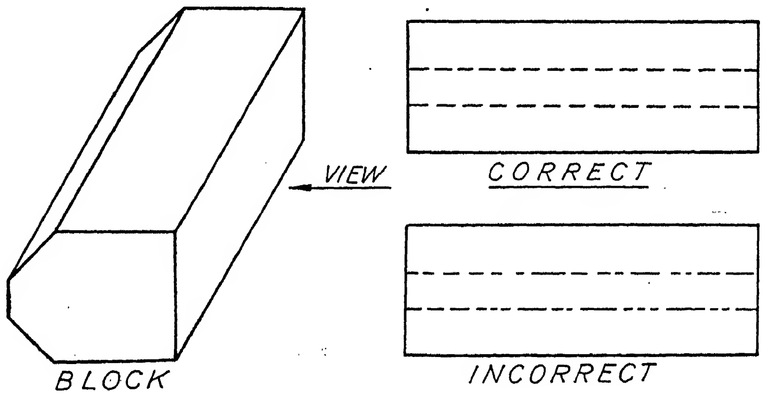


FIG. 4.8.—Drawing invisible outlines.

length of individual dashes may be long or short, depending upon whether the line they compose is long or short, but all dashes within a line should be as uniform in length as can be attained freehand. The length of a dash is never laid out with a ruler. Keeping the spaces between dashes uniform and short will improve the appearance of an invisible outline (see Fig. 4.8).

Exercise

4.4.1. Draw views of the blocks shown in Fig. 4.5, looking at them in just the opposite direction from that indicated by the arrows.

4.5. Break Line.—When it is desired to draw a long part with the same cross section along its entire length except at the ends, much valuable drawing space and drafting time may be saved by "breaking out" the center of the part and showing only the ends. This is indicated on a drawing by means of a break line, a special kind of visible outline that is wavy instead of straight (see Fig.

4.9). In Fig. 4.9*a* is shown a view of a link as it would normally be drawn. Since the link is the same width in most of its length, the center part may be broken out as shown in Fig. 4.9*b* and the true length is indicated by a dimension. Since it is short, the

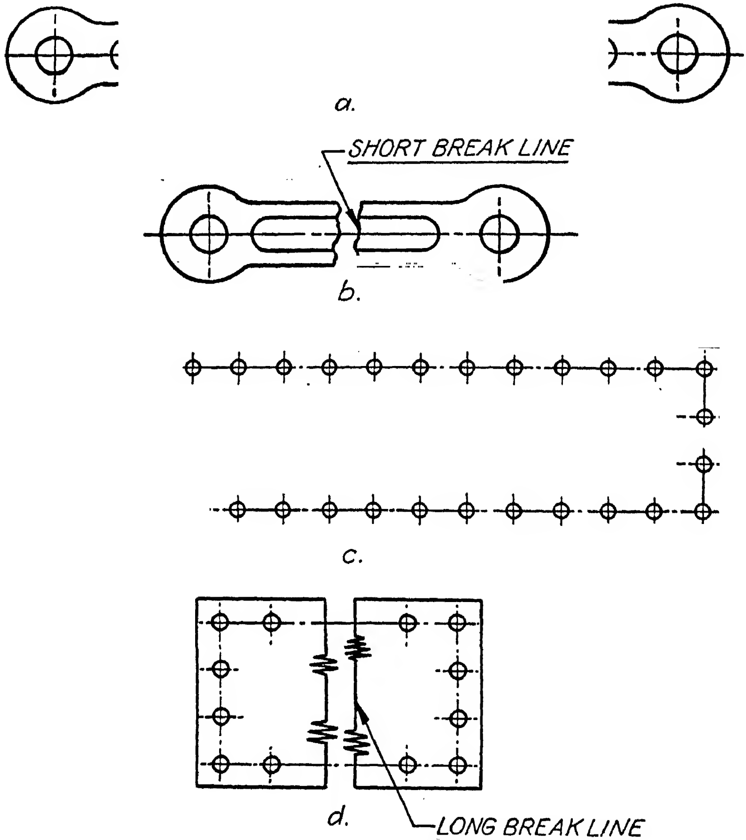


FIG. 4.9.—Break lines.

break line is drawn freehand as a jagged, irregular line. If a wide part, such as is shown in Fig. 4.9*c*, is to be broken, the appearance of the drawing is improved by using a straight line interrupted by a short length of jagged freehand line, as shown in Fig. 4.9*d*. Since the holes along the top and bottom of the part are equally spaced, just a sample of them need be shown. When a small area of an object must be shown in a view but the surrounding

area is of no interest in that particular view, break lines are used, as shown in Fig. 4.10. Two ways of depicting the broken-off view are shown, both representing the same area of a part.

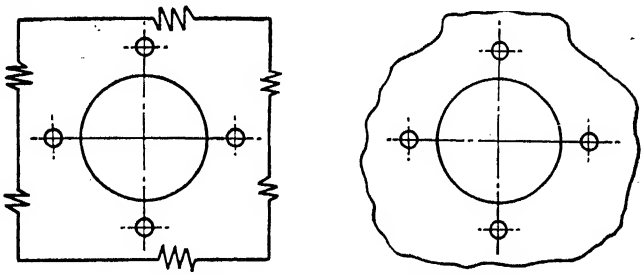


FIG. 4.10.—Break line for a local area.

Which is the neater in appearance? Break lines, like visible outlines, should be uniformly wide and black.

Exercise

4.5.1. Draw the views of the objects in Fig. 4.11 with just enough of the uniform areas showing to indicate what the object is like. The objects

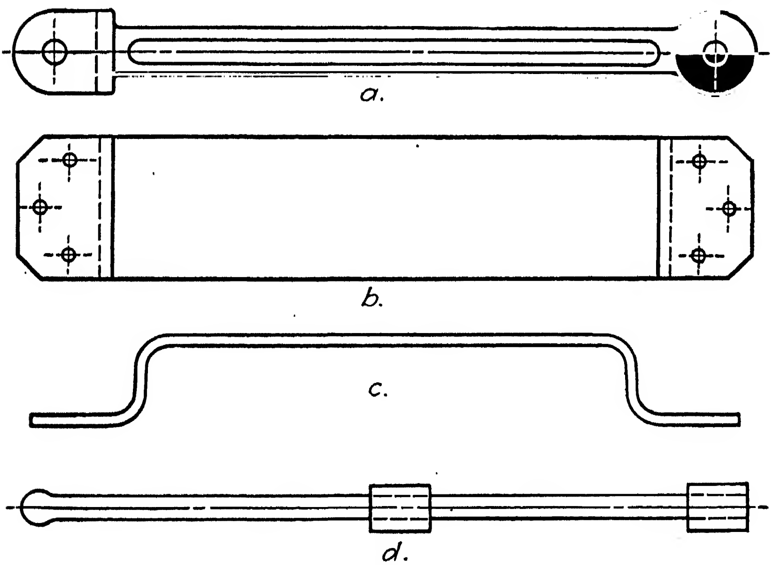


FIG. 4.11.—Exercise in showing breaks.

should be drawn four times as large as in Fig. 4.11, dimensions being obtained by scaling the figures.

NOTE.—How many breaks may be used in Fig. 4.11*d*?

4.6. Center Line.—In the language of mechanical drawing, a straight line about half the width of a visible outline and interrupted occasionally with one short dash always indicates the center of something: a hole, a radius, a cylinder, a tube, or a part itself. This type of line is called a "center line" and some of its uses are shown in Fig. 4.12. In Figs. 4.12*a* and 4.12*b* the center lines indicate the center of the hole and the center of the cylinder; in Fig. 4.12*c*, the left-hand side of the object is just the

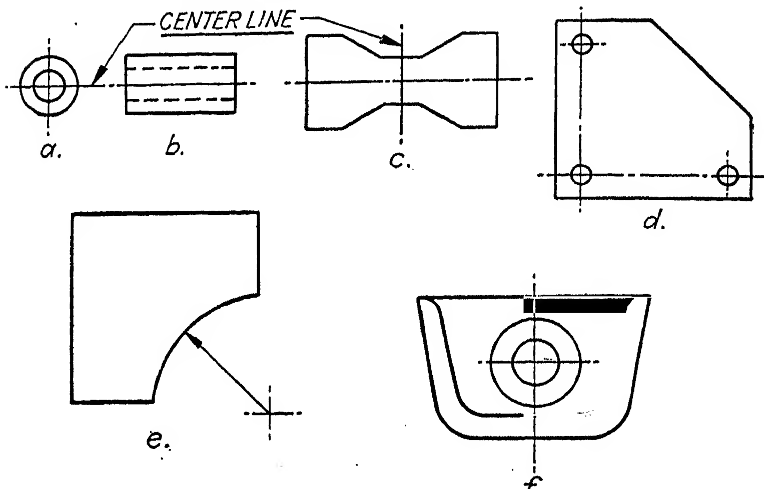


Fig. 4.12.—Center lines.

opposite of the right-hand side of the object (it is said to be symmetrical about both vertical and horizontal center lines); in Fig. 4.12*d*, the centers of the three small holes; in Fig. 4.12*e*, the center of the radius; in Fig. 4.12*f*, the center of the hole and also that the part is symmetrical about the vertical center line.

Center lines should be drawn much narrower than visible or invisible outlines so that they cannot possibly be mistaken for the outlines of the object. The short dashes should interrupt the center line at least every 3 in., and to identify the line readily, a short dash should be used at both ends.

Exercise

4.6.1. In Figs. 4.9, 4.10, and 4.11, draw in all center lines. The objects should be drawn four times as large as shown in the figures, dimensions being obtained by scaling.

4.7. Placing the Views.—If the views previously shown in this chapter are examined, it will be noted that they do not by themselves clearly describe an object. To complete the description, an orthographic drawing usually shows several views of the part (see Fig. 4.13). Individually, views *A*, *B*, and *C* do not tell exactly what the object is like, but by comparing lines

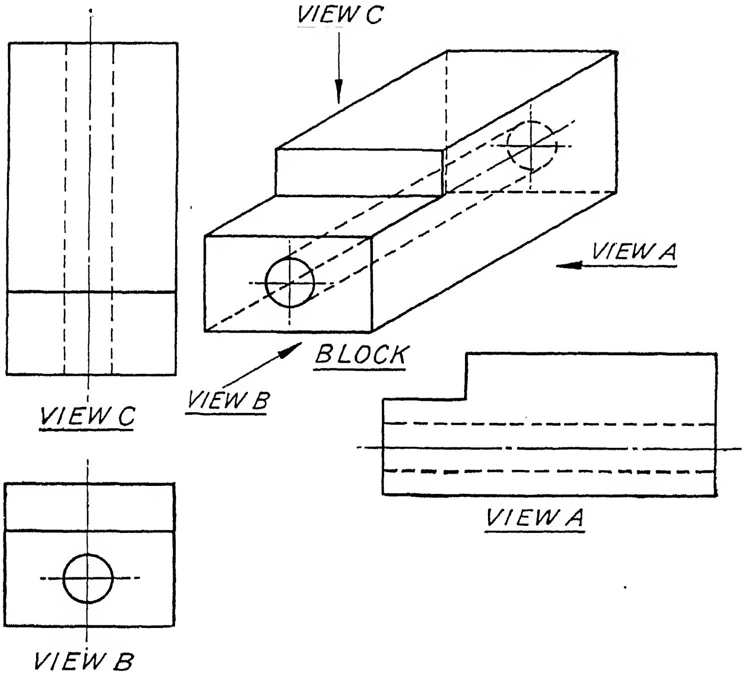


FIG. 4.13.—Orthographic views of a block.

between the views, the meaning of each line becomes clear. In orthographic projection, these three views would be arranged as shown in Fig. 4.14. In view *A*, the meaning of the two horizontal invisible outlines is not clear until, by consulting view *B*, it is seen that they are the projection of the circle in the center of the object. The circle in view *B* and the parallel horizontal invisible outlines in view *A*, therefore, indicate a hole drilled through the part, which is confirmed by the vertical invisible outlines in view *C*. The circle in view *B* without the information in views *A* or *C* could be interpreted either as a hole or as a

cylinder protruding from the block. It will be noted that the horizontal planes and lines of views A and B are at the same level, as shown by the faint lines connecting the two views, and would be drawn for both views with a single setting of the T square. Vertical planes and lines of views B and C are also in the same straight line and would be drawn in both views with a single setting of the triangle on the T square.

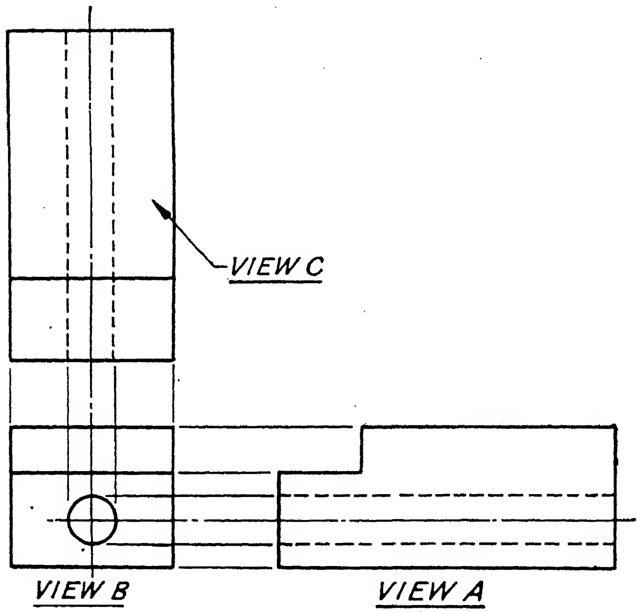


FIG. 4.14.—Arrangement of the views.

For convenience, the views are named: View C, being a view of the top of the part, is called the top view or plan view; view B, being a view of the front, is called the front view or elevation; and view C, being a view of the side, is called the side view or end view. If the block is rotated to the position shown in Fig. 4.15, the same views appear but are located differently. The side view of Fig. 4.15 is the top view of Fig. 4.14 rotated, the front views are rotated, and the top view of Fig. 4.15 is the reverse of the side view of Fig. 4.14 rotated 90 deg. From the two orthographic projections of the same part, shown in Figs. 4.14 and 4.15, it may be inferred that the top, front, and side views

depend entirely upon how the part is located when the views are taken.

The views projected from the block in Figs. 4.13 and 4.15 were quite simple, since the block was located with one of its flat surfaces in the plane of the paper. If, however, the block were rested on one corner, the views would be complicated to draw and hard to understand (see Fig. 4.16). The views should be

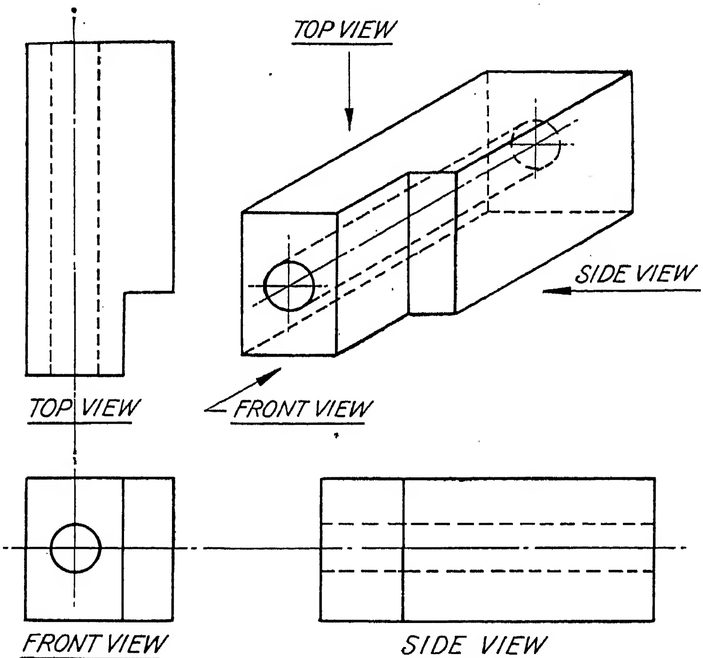


FIG. 4.15.—Rotation of the block.

so chosen that each shows as many of the object's surfaces as possible, either in the plane of the paper, in which case the surfaces will appear in their true size and shape, or on edge, in which case they will appear as lines. The three views are usually arranged in the form of an L, as illustrated in Figs. 4.14, 4.15, and 4.16, with the top and side views at the ends of the L and the front view at the angle of the L. Other arrangements of views are sometimes desirable and may be used as long as they do not violate the rules of orthographic projection.

Exercise

4.7.1. Drawing 15, Views—Orthographic.—Divide a standard drawing form into four equal rectangles and in each draw the top, front, and side views of four of the blocks shown in Fig. 4.17. The dimensions of the blocks, including length, may be scaled directly from the isometric views in Fig.

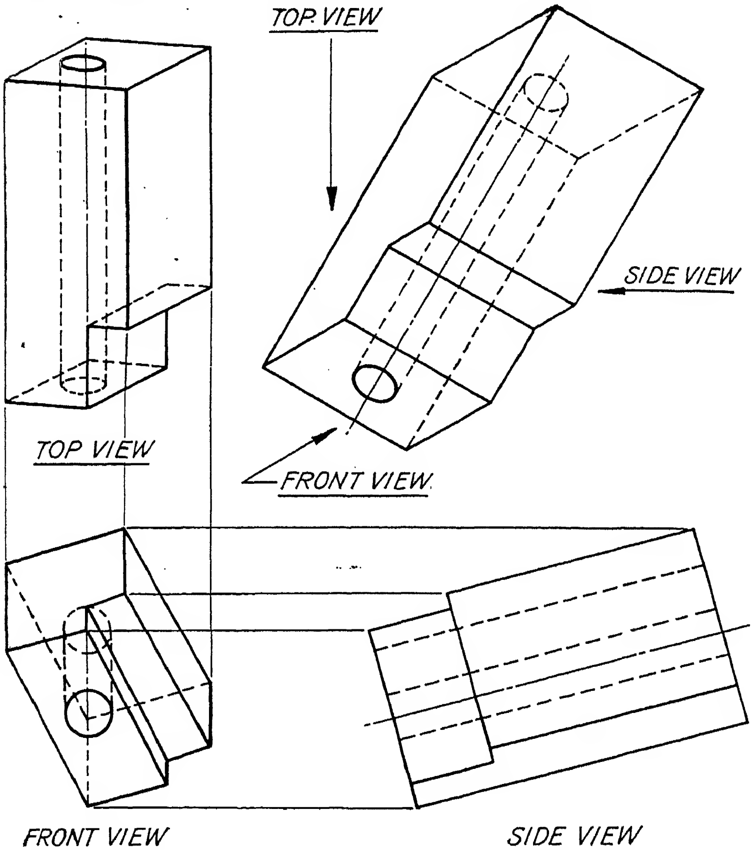


FIG. 4.16.—Improper views of the block.

4.17. The views should be carefully selected with the least number of invisible lines; also located so that the corresponding lines of views are in line with each other. The lines should be uniformly wide and black, with sharp contrast between visible outlines and center lines. The top, front, and side views are *not* so labeled on the drawing.

4.8. Meaning of the Views.—A view may be strictly defined as a projection of an object upon a plane; that means drawing

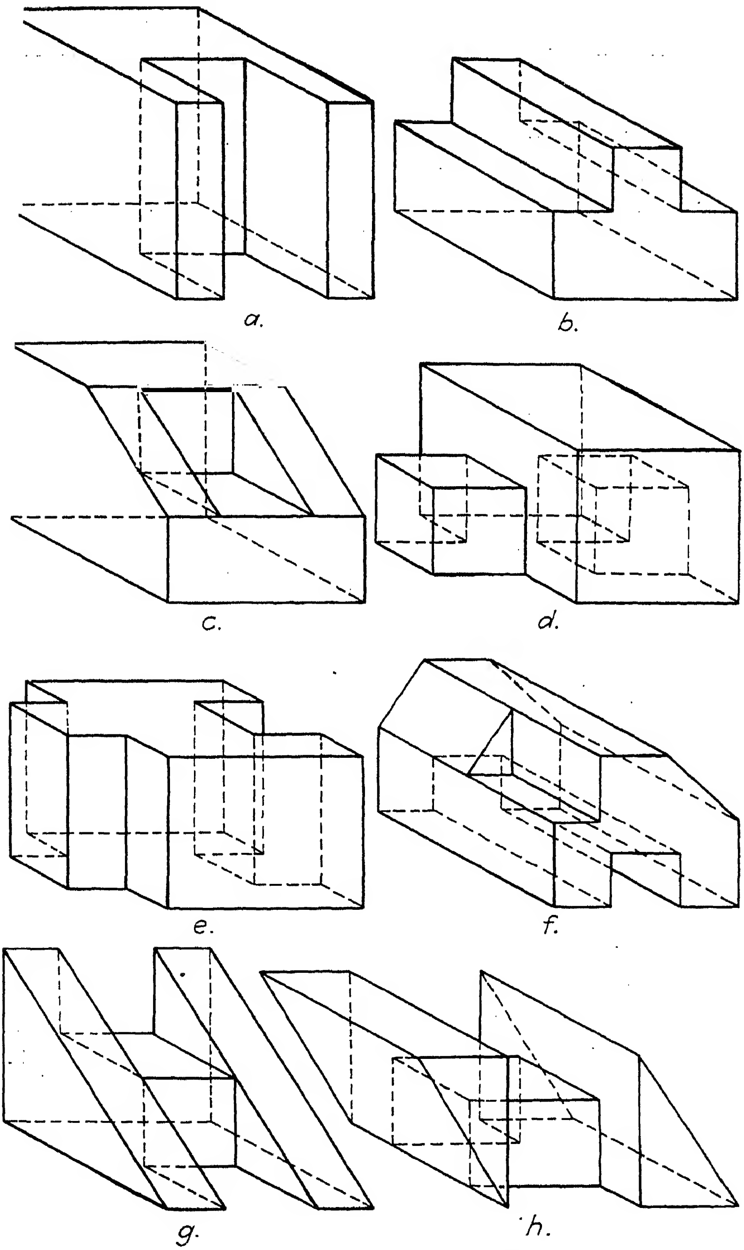


FIG. 4.17.—Projection exercises.

lines from each corner and edge of the object perpendicular to the plane of the view. One illustration of the orthographic arrangement of views is found by considering an object inside a transparent-walled, rectangular box, hinged along lines *AB* and *BC* (see Fig. 4.18). If views of the object were projected on the top, front, and side of the box and the top and side swung into the plane of the front of the box, the three sides would comprise a

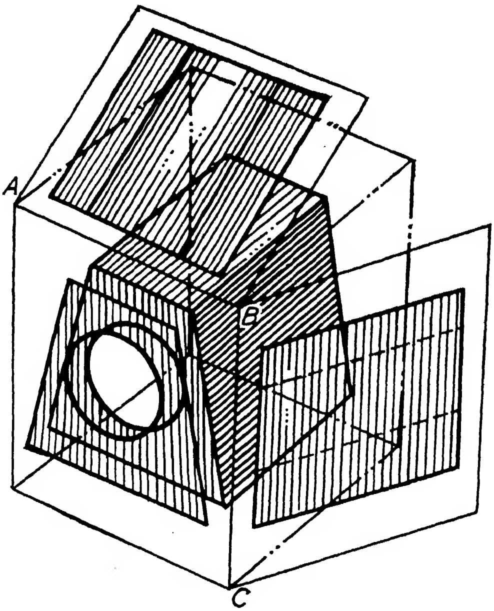


Fig. 4.18.—Projection on a glass-walled box.

typical orthographic projection, showing top, front, and side views. The lines *AB* and *BC*, around which the top and side views are hinged or folded, are called "fold lines." Perhaps a more useful way of thinking about views is to consider one view not as a flat projection of the object, but as the object itself. Then any other view is a projection of the object upon a plane at right angles to the plane of the first view. This plane of the new view is then folded up into the plane of the paper, hinging at its top. In Fig. 4.19, view 6 is a view of the end of view 5. View 7 of the left-hand end of view 6 is exactly the same as view 3 but is rotated.

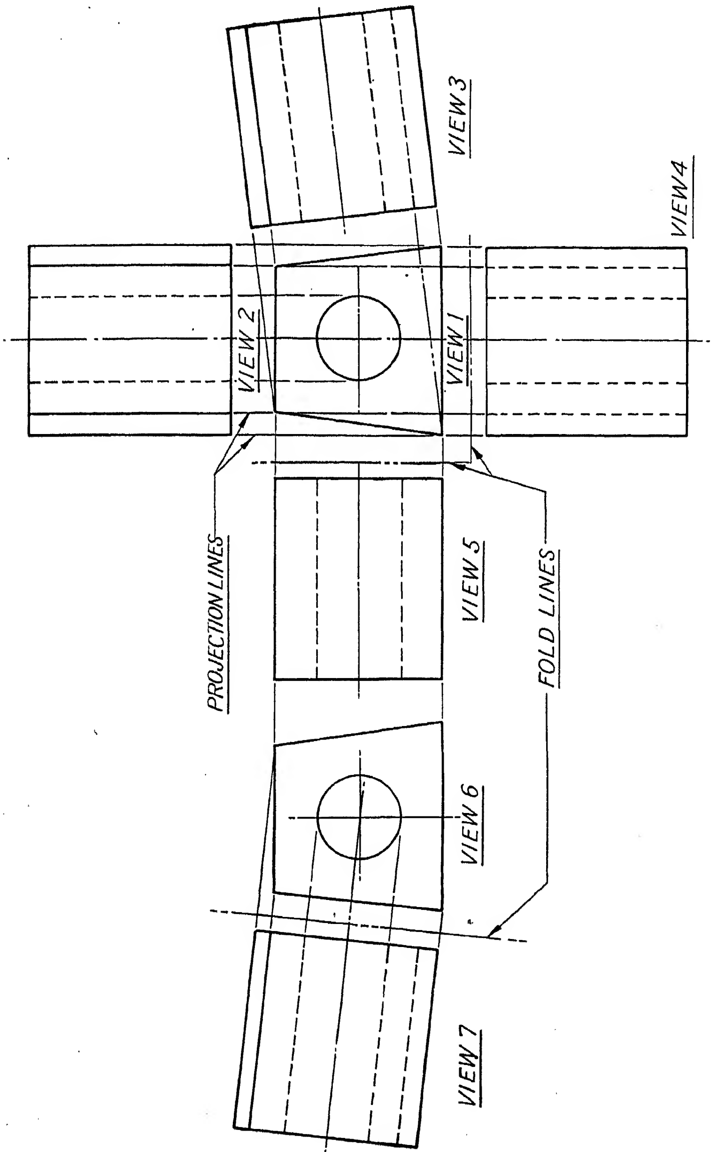


FIG. 4.19.—Repeated projections.

The location of points and lines in a view is determined in one direction by projection from the basic view (view 1) and in the other direction from another projection of the basic view. In Fig. 4.19, view 2 is drawn by projecting the four corners, and the sides and center of the hole from the basic view. The length of these lines must be determined from a projection of view 1, such as views 3, 4, or 5, where the same lines are shown. The front and rear surfaces of the part are in the plane of the paper in view 1, so they will appear as a line perpendicular to the direction in which the view is taken, *i.e.*, perpendicular to the projection lines. The line in view 2 representing the front surface is first drawn, and then a distance equal to the depth of the part, determined from view 3, 4, or 5, is laid off along the projection lines in view 2 to locate the rear surface of the part. Distances perpendicular to the line of projection are projected from view 1; distances parallel to the line of projection are obtained from corresponding distances along the line of projection of some other view derived from the basic view.

Exercise

4.8.1. Drawing 16, Views—Completion of.—Divide a standard drawing form into four equal rectangles. In each rectangle draw the front and side views of the objects shown in Fig. 4.20, and complete by developing the top view. Dimensions may be scaled from the sketches. Views need not be labeled, and projection lines should be erased after completing the views.

Referring again to Fig. 4.19, *surfaces in the plane of a view are seen in their true shape,* such as the front and back surfaces of the object in view 1 or the top and bottom surfaces of the object in view 2. *When a surface is in the plane of the view, any projection of that surface to another view will be a line perpendicular to the projection lines.* The end surfaces of the part are seen in views 2, 3, 4, and 5 as lines perpendicular to the lines of projection of each view. *If a view is projected perpendicular to a line in a view representing a surface, that projection will give the true shape of the surface.* Thus, views 7 and 3 show the true outline of the sloping side of the block. *A line perpendicular to the plane of a view appears as a point and any view of that line will show its true length,* since the line is in the plane of the projected view. Thus the lines of intersection of the four sides of the part appear as points in view 1; in views 2, 3, 4, and 5 these lines are in the plane

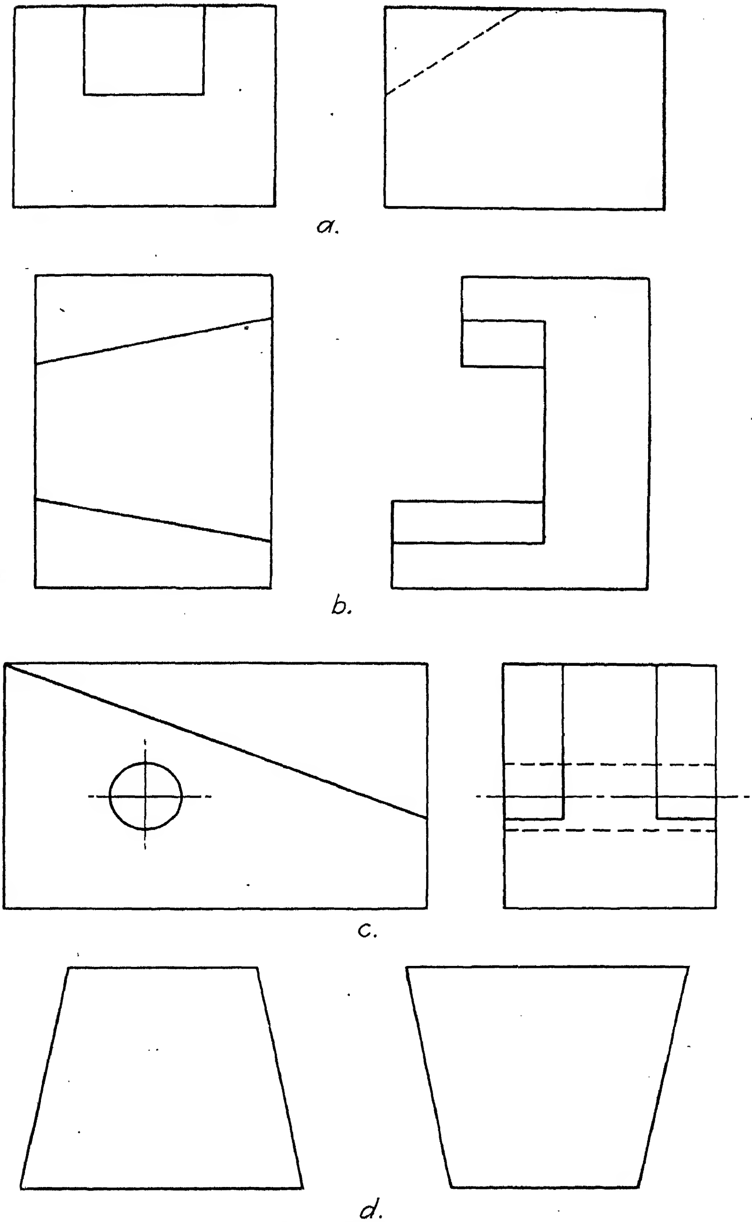


FIG. 4.20.—Completion of views.

of the paper and their lengths are true. *Lines or planes that are not in the plane of the paper are foreshortened.* Thus, in views 2 and 4 the sloping side of the part appears narrower than it really is; in view 2 the intersection of the sloping side and the front of the part appear as a line shorter than it really is, as may be seen by comparing it with the corresponding line in the basic view.

In order to convert an orthographic drawing into a mental picture of the object, it is suggested that a rough survey of all the views be made. Then, each point and line should be identified in all views, working back and forth among views. To obtain a picture of a very complicated object it is often helpful to make an isometric view of it, starting with the general outlines and putting in each detail line and point as they are identified.

Exercises

4.8.2. Drawing 17, Projection—Exercises in.—Proceed as in Drawing 16 with the objects shown in Fig. 4.21.

4.8.3. Drawing 18, Projections—Completion of.—The four orthographic projections shown in Fig. 4.22 are not complete, some lines being purposely omitted. Divide a standard drawing form into four equal rectangles. Draw the three views of each part, adding all omitted lines to the views.

4.9. Preparing a Drawing.—The first step in preparing a drawing is to plan the drawing so that it will depict the part in clear, unmistakable terms and be neat in appearance. The draftsman himself must have a clear picture of the part before he can make a clear drawing; an isometric sketch, as before mentioned, will often help him to clarify the picture in his own mind. The scale should be determined, using full size for complicated parts and reduced scale for large and simple parts. Double or four-times size drawings or views should be used for fine details that would not show up clearly on a full size drawing. The views which will describe the part most clearly should be chosen so as to have as many surfaces as possible parallel or perpendicular to the plane of the view. A view showing visible outlines is preferable to one showing the same surfaces as hidden outlines. A good drawing shows just enough views to convey completely the size and shape of the part. A flat sheet part requires only a flat view, the material gauge giving the thickness of the part. Thus the one-view problems in Chap. 1 were quite complete drawings without additional views. A simple bar stock part, such as a

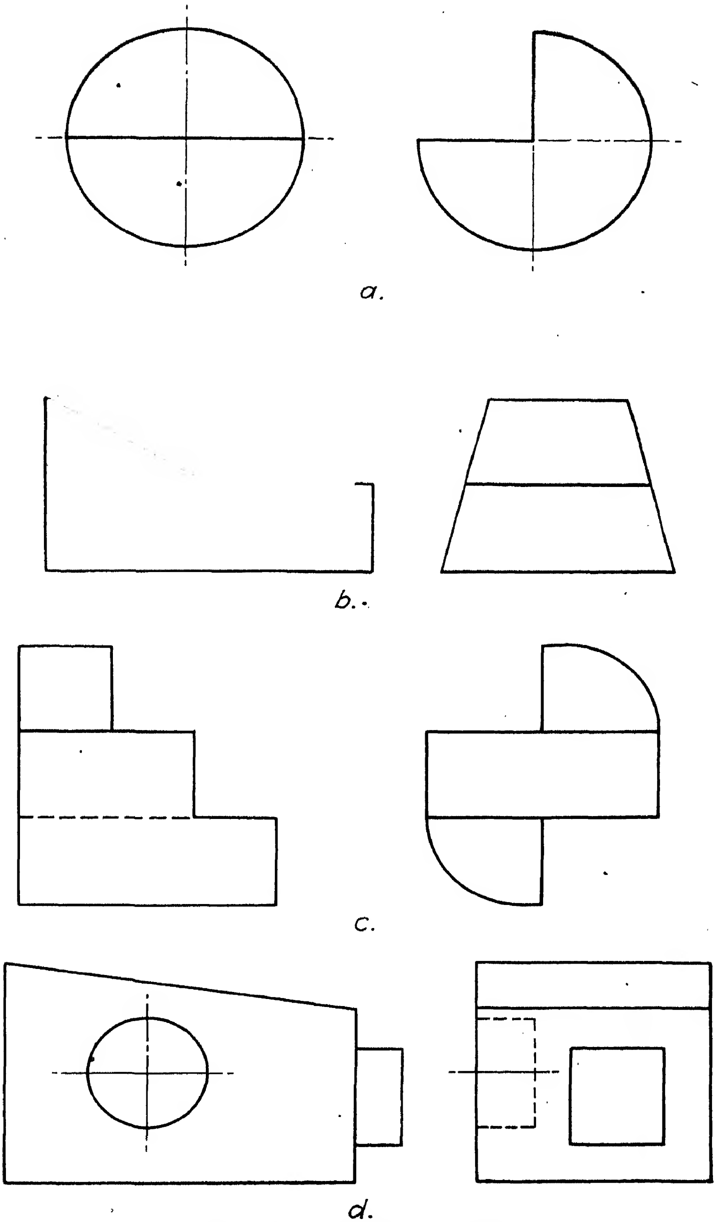


FIG. 4.21.—Completion of views.

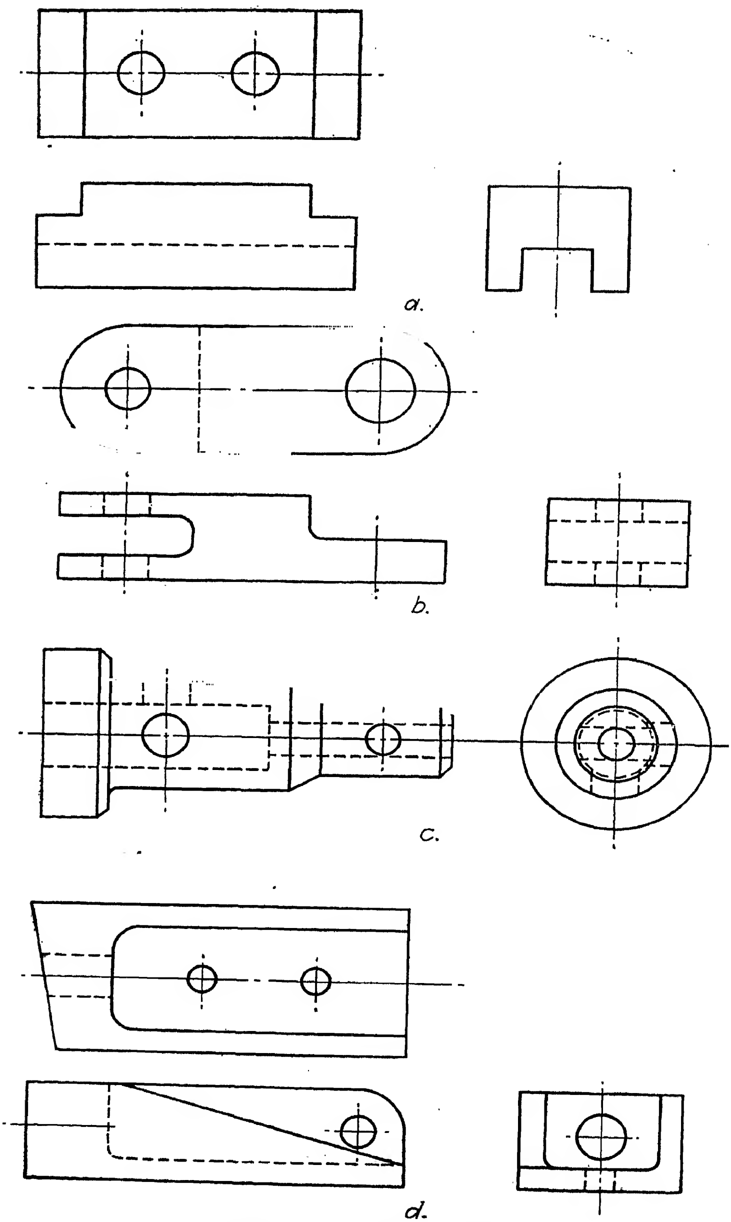


FIG. 4.22.—Missing line problems.

cap screw, a stud, or a shaft, may require only two views: the side view and the front view. Ordinary parts will require the three normal views. Some complicated parts may require, in addition to the three normal views, several auxiliary or helper views for clarity. The draftsman should ask himself: "Is the part clear without further views? Can any of the planned views be omitted without making the part less clear?" Too many views are a waste of drafting time; too few views are a source of confusion and error to the men in the shop who must use the drawing.

Next, the views should be centrally located in the drawing space to give the drawing a balanced appearance. A suggested guide is to place paper rectangles representing the size of each view on the drawing paper or to sketch reduced scale rectangles on a piece of scratch paper to determine the location of the views. The center lines of parts and the radius centers should then be drawn on a prepared drawing form, and the radii should be drawn in lightly. Visible and invisible outlines are next drawn lightly. It will be found helpful to work back and forth between views, completing a line or surface of the part in all views rather than trying to make one view complete. The view which shows the most complicated or indexing contour of the part is the best one to start with, since those contours may be projected to the next view or views. At this stage in the drawing, it is a good idea to check dimensions so that errors may be located at a time when they are easily corrected. Auxiliary lines for dimensions, leaders for notes, and guide lines for notes should be added (these lines will be discussed in detail in Chap. 6). Visible and invisible outlines may now be heavied up and the lettering added to the drawing. Finally, the drawing should be checked for completeness. The draftsman should ask himself this question: "With nothing but this drawing for information, could I build the part it describes?"

4.10. Problems.—The parts shown in the following isometric views should be drawn full size, each on a standard drawing form. Top, side, and front views should all be shown, even if not strictly necessary, in order to gain additional practice in projection. The views need not necessarily be arranged in the L form, if another arrangement of the views is found desirable. All dimensions required for laying out the views are contained in the isometric sketches, and the parts should be laid out to scale as accurately as possible. Care should be exercised to obtain uniform line width and blackness, and visible and invisible outlines should contrast sharply

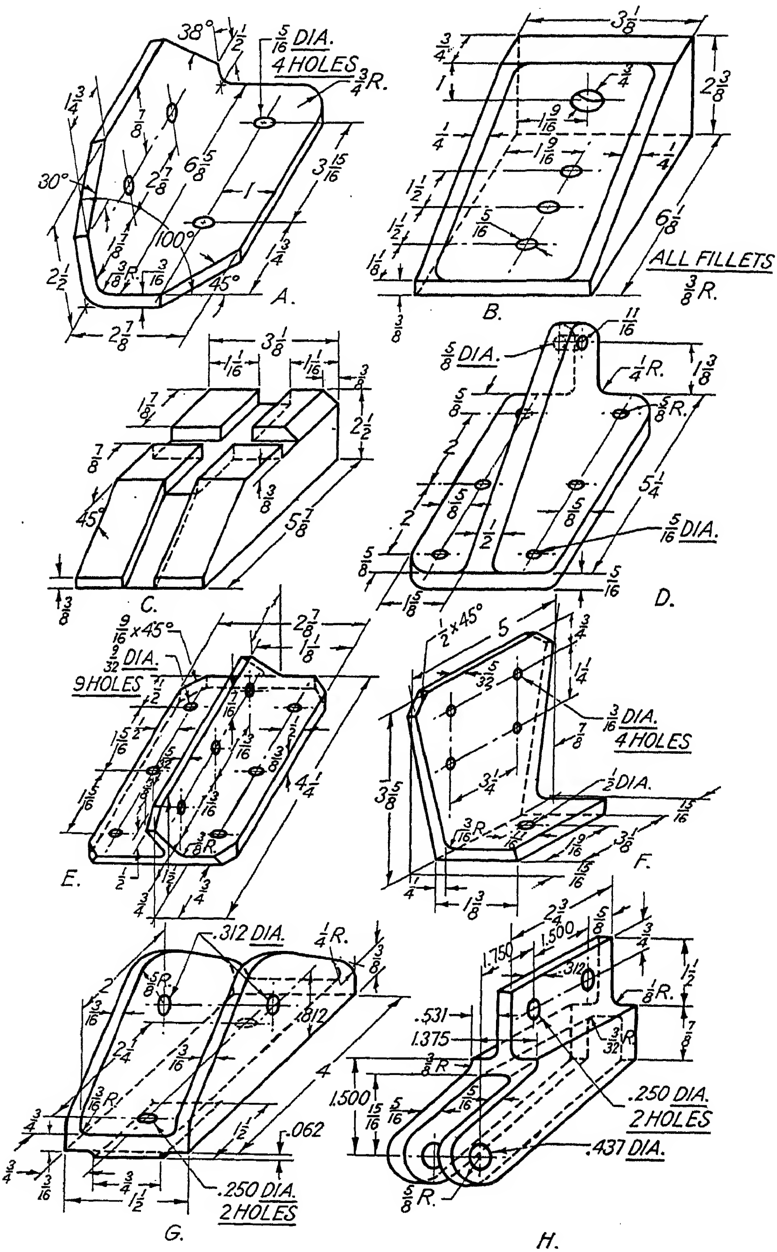


Fig. 4.23.—Problems.

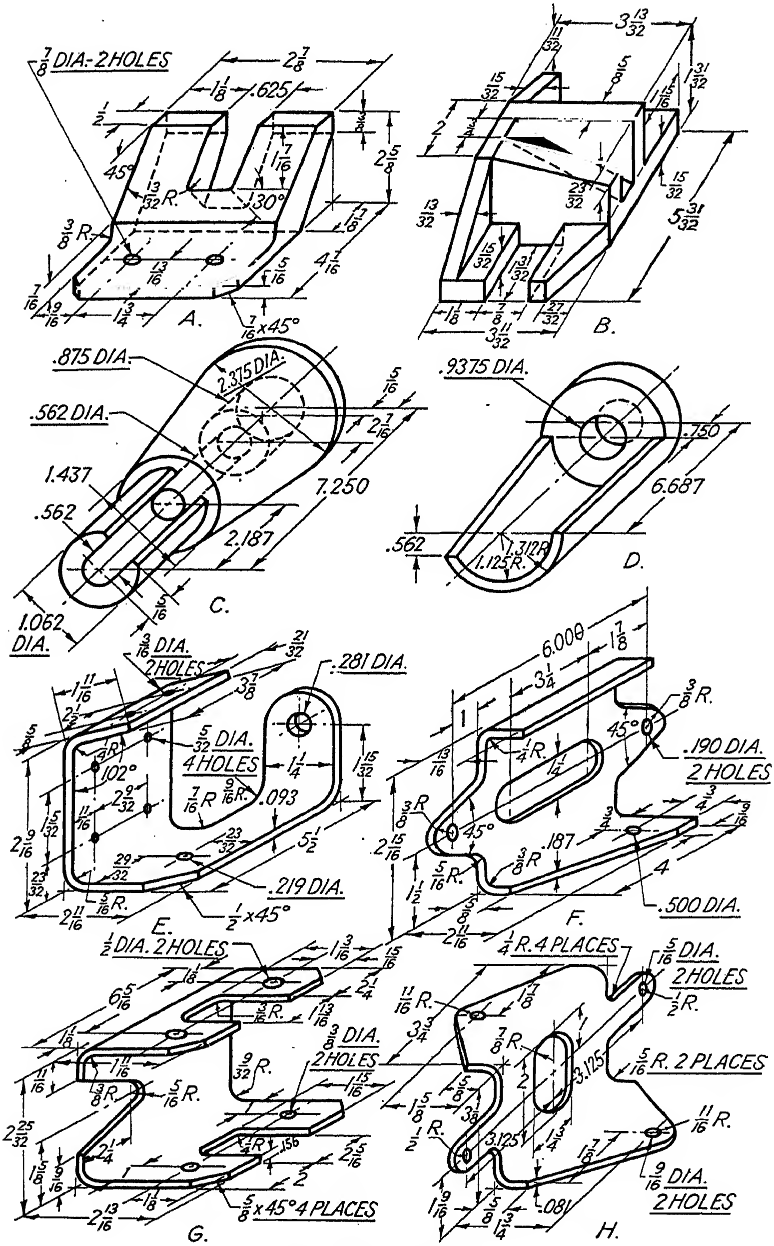


Fig. 4.24.—Problems.

with center lines to make the object stand out from the drawing. The titles and drawing numbers to be used are noted individually below.

4.10.1. Drawing 19, Angle—Wing Rib Attaching (Fig. 4.23*a*).
4.10.2. Drawing 20, Fitting—Aileron Front Spar (Fig. 4.23*b*).
4.10.3. Drawing 21, Block—Test Bearing (Fig. 4.23*c*).
4.10.4. Drawing 22, Lug—Tension Spring Anchor (Fig. 4.23*d*).
4.10.5. Drawing 23, Tee—Nacelle Frame Attach (Fig. 4.23*e*).
4.10.6. Drawing 24, Angle—Seat Support (Fig. 4.23*f*).
4.10.7. Drawing 25, Fitting—Door Hinge Support (Fig. 4.23*g*).
4.10.8. Drawing 26, Anchor—Flap Restraining Spring (Fig. 4.23*h*).
4.10.9. Drawing 27, Stop—Elevator Operating Bell Crank (Fig. 4.24*a*)
4.10.10. Drawing 28, Block—Jig Stop (Fig. 4.24*b*).
4.10.11. Drawing 29, Pin—Special Tapered (Fig. 4.24*c*).
4.10.12. Drawing 30, Fitting—Tube Splice (Fig. 4.24*d*).
4.10.13. Drawing 31, Clip—Seat Latch Retainer (Fig. 4.24*e*).
4.10.14. Drawing 32, Channel—Pulley Bracket Support (Fig. 4.24*f*).
4.10.15. Drawing 33, Channel—Flap Rib Reinforcing (Fig. 4.24*g*).
4.10.16. Drawing 34, Zee—Tab Hinge Support (Fig. 4.24*h*).

CHAPTER 5

SECTIONS AND AUXILIARY VIEWS

5.1. Definition of a Section.—Three views or less have been sufficient to describe completely and clearly the blocks and simple parts which have been used as illustrations, exercises, and problems in the previous chapters. To define a more complicated part completely on an easily understood drawing, more information may be required than can be given in the top, front, and side views. Figure 5.1 shows an ordinary forged link as it would

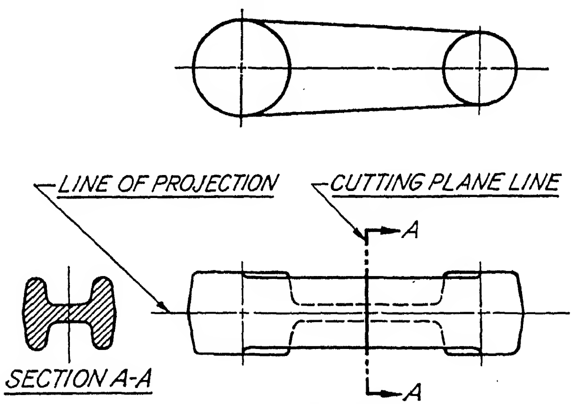


FIG. 5.1.—A forged link.

be depicted by two conventional orthographic views and an additional cross-sectional view. If the cross section were not included among the views, would the drawing clearly define the part?

A cross section is always a view of the inside of an object. In Fig. 5.1, if the link were sawed through along the plane of the double-dash line and the half of the link *behind* the arrows were removed, section A-A would be a partial end view of the remainder of the link. It should be noted that section A-A shows only the material at the plane of the cut and does not show any detail beyond the cut. This is typical of sections, since their purpose is to show the details of a local portion of an object. Additional

details of the background may be shown if necessary or if helpful in locating the section or describing its relation to the object. The exact location where the section is taken is shown by a cutting plane line, which consists of a long, wide straight line broken intermittently by two short dashes. In the section view itself, the area of the cut is shaded by using section lines. These are narrow lines slanting obliquely, usually at 45 deg. to the

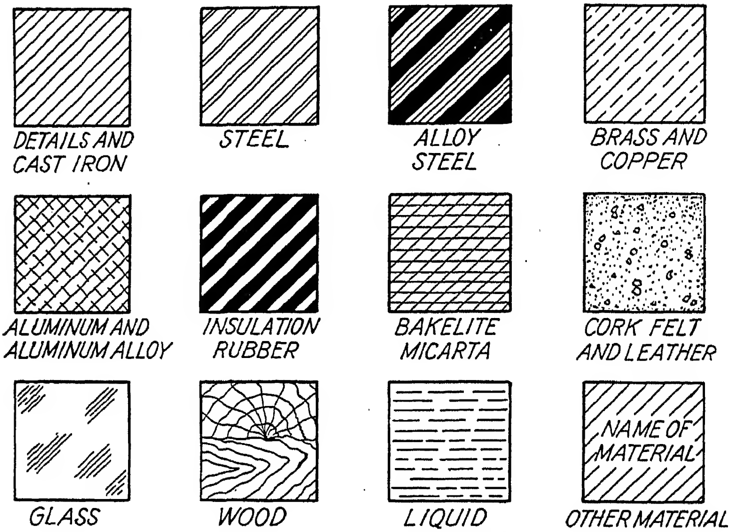


FIG. 5.2.—Cross section coding.

rectangular axes of the section and spaced equal distances apart, approximately $\frac{1}{16}$ to $\frac{1}{8}$ in. If the section view shows any part of the object not in the cutting plane, that part outside the cutting plane is not crosshatched with cross-sectional lines. Sections of assembly drawings, consisting of several parts fabricated of different materials, identify the various materials by distinct types of cross-sectional line patterns. The section-line codings used in assembly drawings for different types of materials are shown in Fig. 5.2. The cast-iron coding is used for all types of detail or single part drawings, regardless of the material of which they are composed.

5.2. Location of Sections.—Since a section is a view of the inside of a part, *it must be projected like a view*. In Fig. 5.1, the projection line of the section is perpendicular to the cutting

plane line, and the section shows the part lying on its side so to speak. The section would not be correct had it been rotated to stand up or to lie at an oblique angle. Unlike normal views, sections may be placed at any convenient location on a drawing if necessary, as shown in Fig. 5.3; this does *not* mean, however, that they may be rotated. Of the five section A-A's shown, projection 1 is the most desirable and should *always* be used if

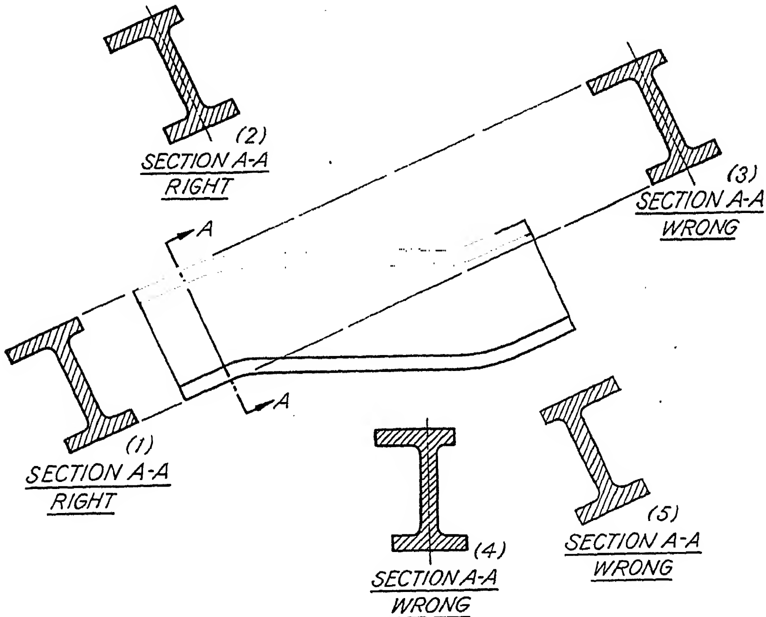


Fig. 5.3.—Location of sections.

room permits. It is a direct projection from the main view and is placed *behind* the arrows. If there is no room behind the arrows, the view may be moved to any convenient location above or below but *not* in front of the arrows. Projection 2 shows a satisfactory alternate location of the section; it should be noted that the section slopes exactly the same as section A-A in projection 1. Although it is not rotated, projection 3 is wrong in that it is in front of the arrows and gives the impression that the long leg of the I beam extends up from the paper in the main view instead of down from the paper, as it actually does. Projection 4 is wrong in that the view is rotated from its sloping

position in projections 1, 2, and 3 to an upright position. Projection 5 is not rotated and is placed in an acceptable location on the drawing but is shown in the opposite direction from that indicated by the cutting plane arrows. Projection 5 is wrong because it indicates that in the main view the long leg of the I beam extends up from the paper rather than down.

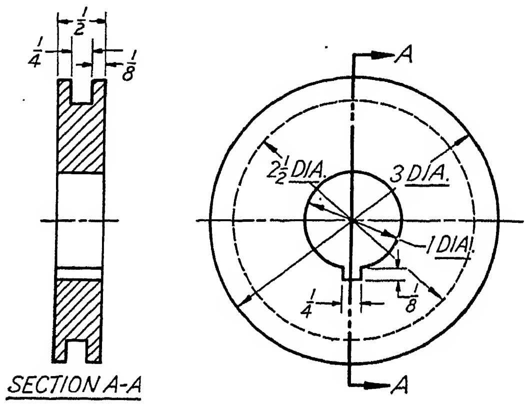


Fig. 5.4.—Pulley—utility.

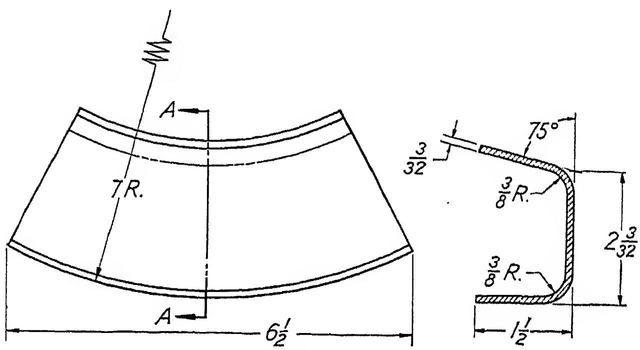


Fig. 5.5.—Splice—door jamb.

Exercise

5.2.1. Drawings 35 to 38.—On standard drawing forms, draw full size the views and cross sections shown in Figs. 5.4, 5.5, 5.6, and 5.7. Refer to Fig. 2.16 for cross-sectional letters. Dimensions given in the sketches are for determining the proportions of the part and need not be copied on the drawing. The titles of the parts given in the figures should be used on the drawings.

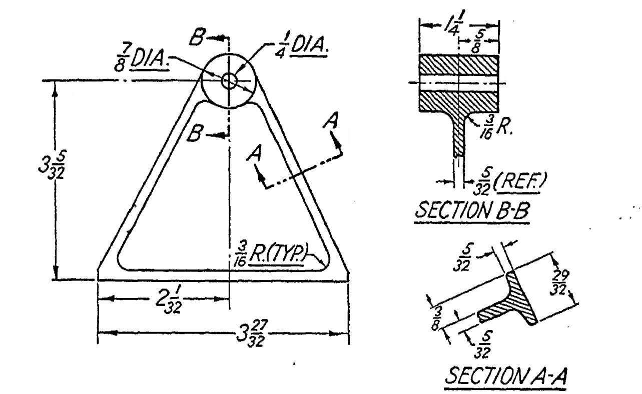


Fig. 5.6.—Support—emergency release lever.

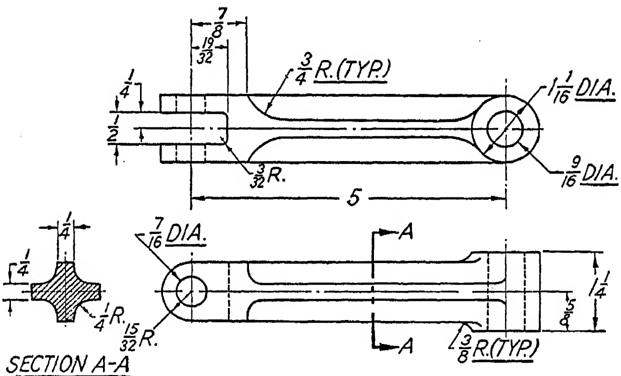


Fig. 5.7.—Link—landing gear locking.

5.3. Assembly Sectioning Convention.—In sections of assembly drawings the section lines of parts adjacent to each other

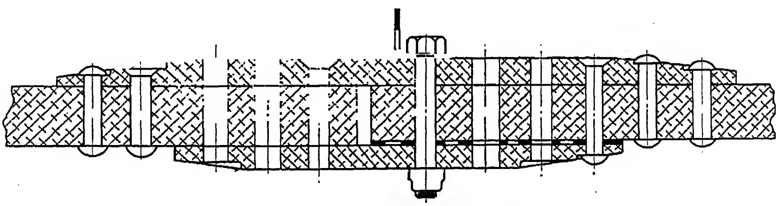


Fig. 5.8.—Assembly section conventions.

slope in opposite directions to distinguish them. Attaching parts, such as bolts, nuts, rivets, washers, cotter pins, etc., are *not* cross-sectioned but are shown as though the main object

had been cut without the attaching parts, and the full attaching part had been slipped in afterward. A solid part the shape of which is perfectly clear, such as a shaft or a pin, is also not cross-sectioned. The cross section of a very thin sheet would be hard to fill with section lines and is sometimes indicated by blacking in sections about $\frac{3}{16}$ in. long and $\frac{3}{16}$ in. apart. The above assembly section conventions are illustrated in Fig. 5.8.

5.4. Special Types of Sections.—Cross sections are sometimes shown without specifically pointing them out by a cutting plane-line and a special view. The most common type is the broken-out or quarter section. Essentially, a part of the material is cut away so that the inside of the object may be seen. Figure 5.9 shows the front view of part of a hydraulic cylinder, the remainder having been broken off because of limitations of space. The upper half of the front view is a cross section and shows the relation of the cylinder, cylinder head, piston, piston rod, packing, and packing nuts. The lower half of the front view shows only the visible outer contour of the complete cylinder assembly; all dotted lines, representing the inner construction, invisible threads, etc., are omitted from this part of the view, since they would be confusing and would only duplicate the information clearly given in the sectioned upper half of the view. The side view of the cylinder, like the bottom half of the front view, consists of visible outlines only, for the invisible outlines would confuse the clear description of the cylinder contained in the sectioned half of the front view.

It is always permissible to omit invisible outlines in any view if they are confusing and other sections or views adequately define the shape of the part. Figure 5.10 shows two end views of a shaft. The view on the left, showing all the invisible outlines, is quite confusing and only by taking great pains can the significance of each line be determined; the view on the right shows only the bold details of the part. Both views tell equally well that the part is composed of cylindrical elements of different diameters; these diameters would be indicated by dimensions on the side view. Details of hidden parts of an object may be omitted in a view if a section or another view explains these details.

Sections may also be broken out or may be superimposed directly on the main view of an object if the sections do not cover

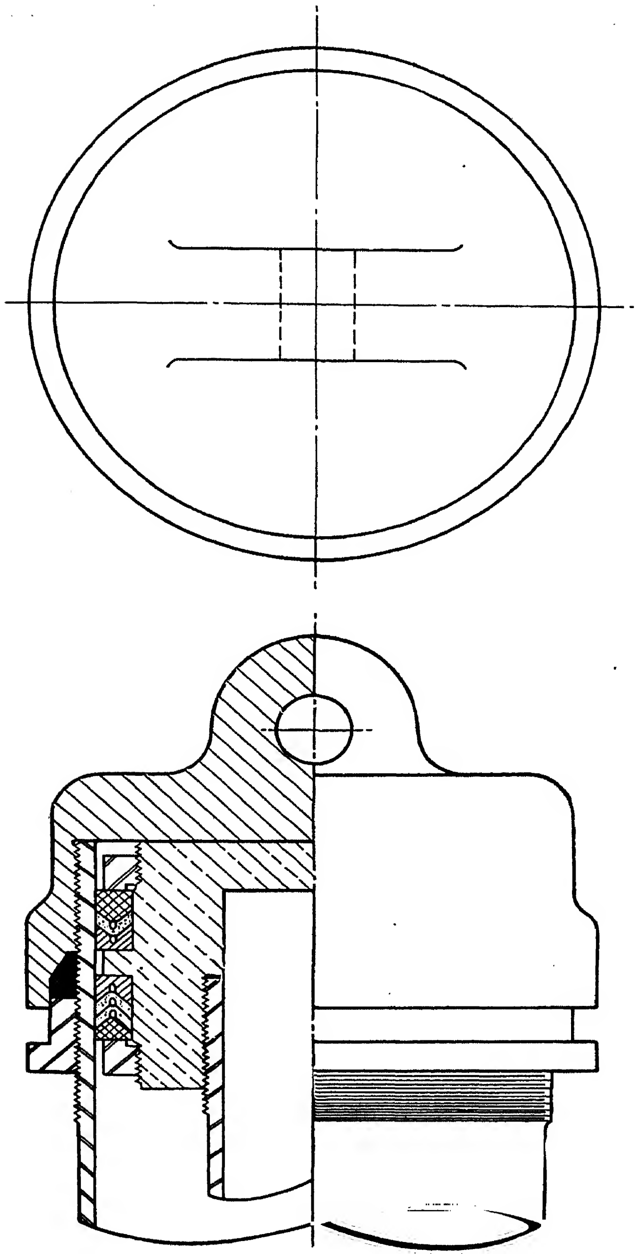


FIG. 5.9.—Quarter section.

up other information. The broken-out section of Fig. 5.11*a* shows that the object has an H-type cross section. Figure 5.11*b* shows that the flat sheet has a bulb angle riveted on the near side

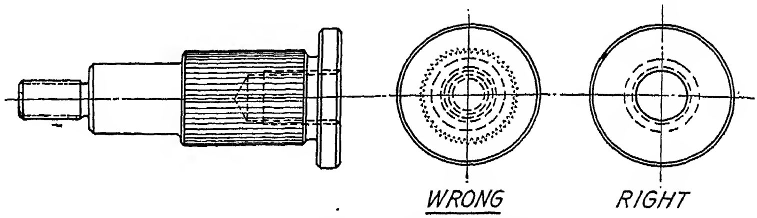


FIG. 5.10.—Omission of invisible outlines.

of the sheet and a plain angle on the far side. In this type of section, the direction in which the view is taken may be indicated by a break line and arrows, without assigning a letter to the

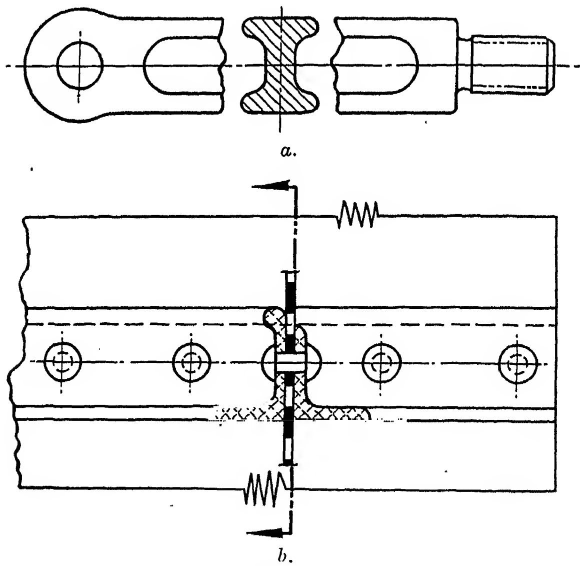


FIG. 5.11.—Broken-out sections.

section. It should be noted that the section was carefully laid in an area where it did not interfere with the picture of the rivet pattern.

In partial views certain drafting conventions permit parts to be described by a sort of section that does not necessarily show

section lines. Figure 5.12 shows some of these conventions. Figures 5.12*a* and 5.12*b* show how breaks in tubes and cylinders are represented. These breaks give nearly as good a visual

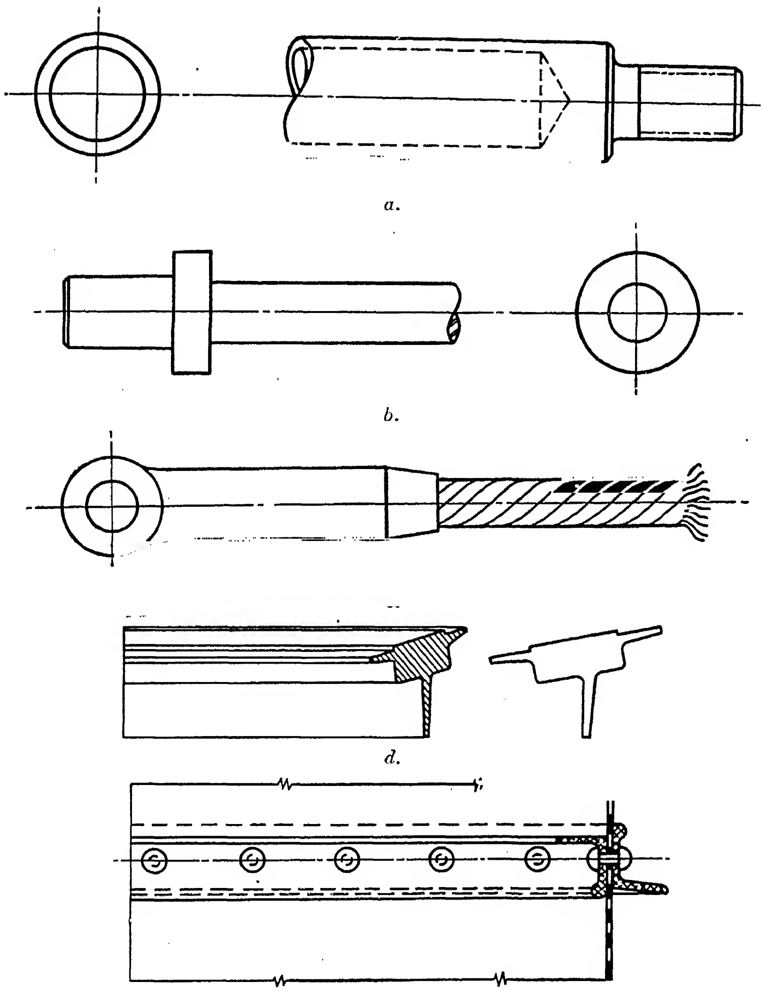


Fig. 5.12.—Sections indicated at breaks.

description of the cross section of the part as do the end views shown adjacent to the break. Figure 5.12*c* shows a typical break for rope or cable, the small lines representing the frayed

end. Figures 5.12*d* and 5.12*e* show breaks in extruded sections, which indicate the shape of the extrusion. The exact size of the extrusion is not truly depicted. The cross-sectioned break indicates the meaning of the visible and invisible outlines in the main view.

Sections should never be used to repeat a story told clearly elsewhere on a drawing. By choosing the cutting plane carefully, one section may serve to show what would require two sections chosen at random. The cutting plane in Fig. 5.13,

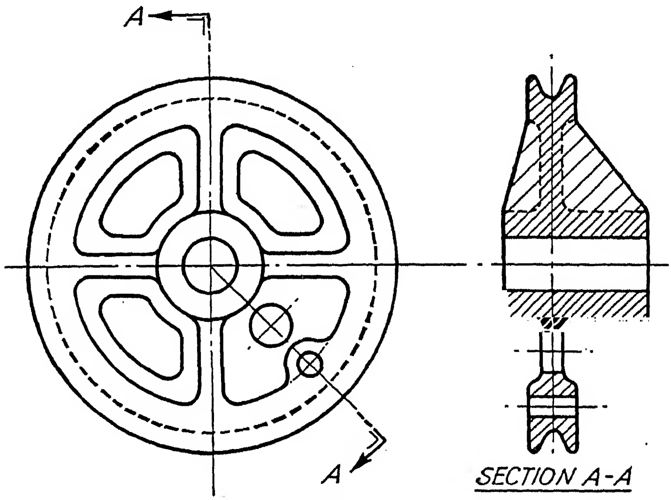


FIG. 5.13.—Oblique section.

instead of being a single straight line, passes through the vertical web at the top of the pulley and angles off through the lightening hole and the boss at the bottom of the pulley. The projection of the section was taken perpendicular to the top part of the cutting plane but could have been taken perpendicular to the bottom part of the cutting plane as well; it could not be projected at random. However, the cross section is shown not according to strict orthographic projection, since the angled-off part of the section is rotated into the plane of the paper; the center lines of the two lower holes in the section will not project back to the hole centers in the front view. It will be noted that the cross-sectional lines in the reinforcing webs at the top of the section are spaced twice as far apart as those in the main part of

the section, and that the main vertical web of the pulley is shown by invisible outlines, since it is behind and hidden by the reinforcing web. This is conventional drafting practice, since it enables the cross section to show both the special webs at the cutting plane and the typical construction beyond it. The choice of the dog-leg cutting plane further explains the cut-out in the main web, the boss, and the drilled hole. Thus, the front view and one section completely describe the pulley without the use of any further views.

Exercises

5.4.1. Drawing 39, Pulley—Flight Control.—On a standard drawing form, draw the view and the section of the pulley shown in Fig. 5.13. All webs are $\frac{1}{4}$ in., all fillets $\frac{3}{16}$ in. radius, and all rounded corners are $\frac{1}{16}$ in. radii.

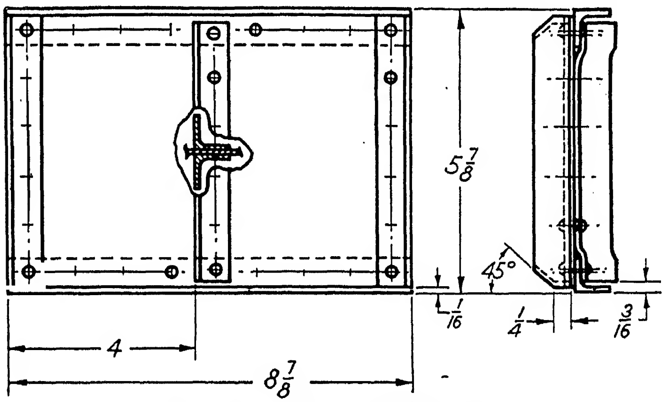


FIG. 5.14.—Beam—lateral support.

The diameter of the central hole is $\frac{9}{16}$ in., the pulley rim is $\frac{1}{2}$ in. thick, the outer diameter is 4 in., and the cable slot is $3\frac{1}{2}$ in. in diameter. All other dimensions required to draw the pulley may be obtained by scaling Fig. 5.13 and by multiplying the scaled dimensions by two.

5.4.2. Drawing 40, Beam—Lateral Support.—Draw the beam shown in Fig. 5.14. All angle stiffeners are $\frac{1}{16}$ in. thick, with both legs $\frac{3}{4}$ in., and with $\frac{3}{32}$ in. corner radii. Sections should be broken out of the vertical stiffeners at both ends of the beam, similarly to that shown in the middle stiffener. It should be noted that the end stiffeners consist of a single angle placed only on the near side of the web, the thickness of which is $\frac{1}{32}$ in. The rivet heads are represented by $\frac{1}{4}$-in.-diameter circles and are spaced approximately 1 in. apart and $\frac{5}{16}$ in. away from the toe of the angles, except at the ends of the center stiffeners where they are $\frac{1}{4}$ in. from the ends of the stiffeners. All the rivet heads need not be shown but may be indicated by short crosslines indicating the rivet centers.

5.4.3. Drawing 41, Body—Hand Pump.—Draw the casting shown in Fig. 5.15. All fillets have 3/16 in. radii.

5.4.4. Drawing 42, Link—Aileron Control.—Draw the casting shown in Fig. 5.16. All webs are 5/32 in. thick, and all fillets have 3/16 in. radii. The

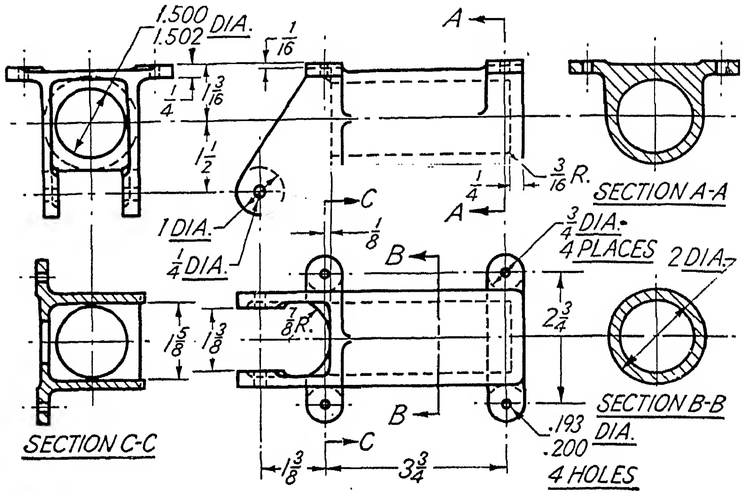


Fig. 5.15.—Body—hand pump.

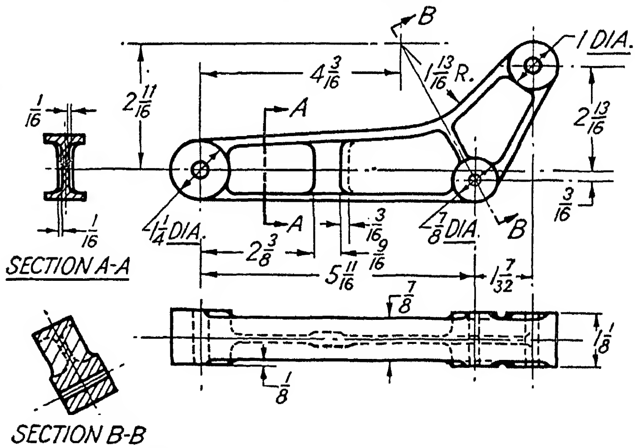


Fig. 5.16.—Link—aileron control.

left-hand hole is 5/16 in. in diameter, the center hole is 3/16 in. in diameter, and the right-hand hole is 1/4 in. in diameter.

5.4.5. Drawing 43, Bracket—Pulley Support.—Draw the bracket shown in Fig. 5.17. All webs are 5/32 in. thick, and all fillets are 3/16 in. in radius unless otherwise noted.

5.5. Simple Auxiliary Views.—Previous examples have shown views of rectangular parts in which planes or center lines were either in the plane of the paper or perpendicular to the plane of

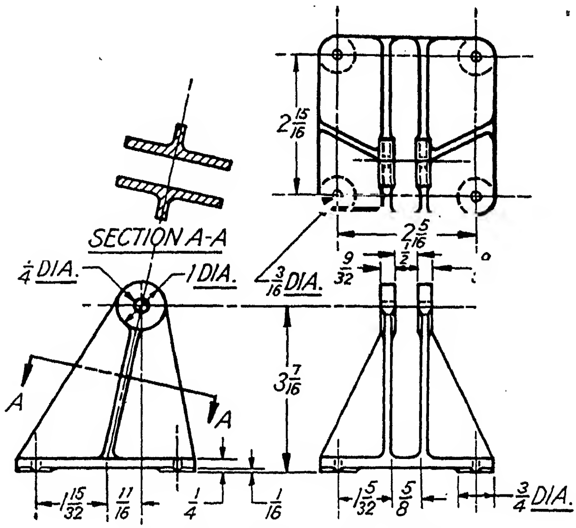


FIG. 5.17.—Bracket—pulley support.

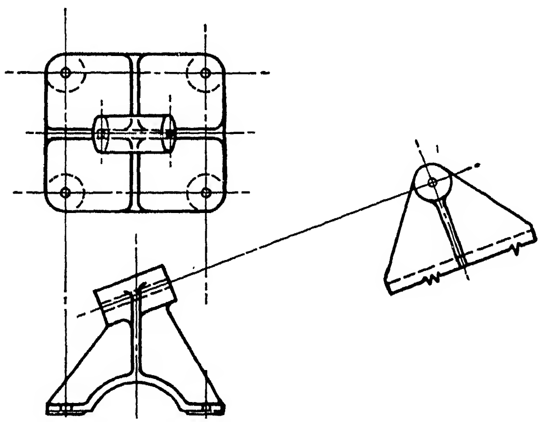


FIG. 5.18.—Bracket—engine control bell crank.

the paper. Such simple objects are the exception rather than the rule in aircraft work. In order to show complicated parts clearly, auxiliary or extra views are required. Figure 5.18

shows the usual top and front views of a bell crank bracket and a special view looking along the center line of the crank lug instead of an end view. The top and front views adequately describe the base and supporting webs of the bracket, but they do not tell the exact shape of the lug. The special view shows that the pulley lug is round and is drilled; it also shows that the supporting webs are tangent to the pulley lug. It should be noted that the base and part of the supporting webs are not shown in the special view, since the base would be out of the plane of the paper and therefore would be complicated to show and to understand. Since the sole purpose of the special view

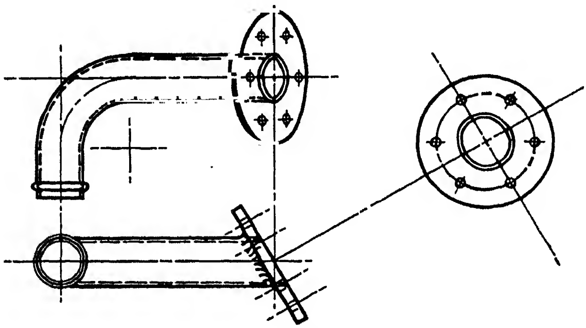


Fig. 5.19.—Fitting—tube.

is to describe the crank lug and its connection to the supporting webs, all irrelevant information is omitted. An end view could be added to the drawing but is not, since it would add nothing to the information already conveyed by the three views shown and would require additional drafting time. It cannot be emphasized too much that a drawing should carry all information necessary to delineate the object completely, but should not show views or sections that repeat information or that do not add to the clarity of the drawing. Figure 5.19 shows the top and front views of a tube connecting fitting and in addition shows a true view of the attaching face of this fitting. The true view shows the shape of the attaching face and the arrangement of the attaching holes but does not show any detail of the bent tube, except where it intersects the attaching face. This true view is obtained by projecting it perpendicular to the face in the view showing the surface on edge so that in the auxiliary view, the attaching face lies in the plane of the paper. Thus, a true

view may be obtained by projecting it normal to the line or surface of which it is desired to obtain the true view.

Exercises

5.5.1. Drawing 44, Bracket—Engine Control Bell Crank.—Draw the bracket shown in Fig. 5.18, full size. Since Fig. 5.18 is quarter size, linear dimensions scaled from the figure must be multiplied by four before using. All webs are $\frac{5}{32}$ in. thick, all fillets are $\frac{3}{16}$ in. in radius, and all holes are $\frac{3}{16}$ in. in diameter.

5.5.2. Drawing 45, Fitting—Tube.—Draw the fitting shown quarter size in Fig. 5.19 full size on a standard drawing form. The tube is 1 in. in diameter with a $\frac{1}{16}$-in. wall. The bead on the end is formed of $\frac{1}{8}$ in. radii and projects $\frac{1}{16}$ in. from the outside diameter. The end plate is $2\frac{3}{4}$ in. in diameter, $\frac{3}{16}$ in. thick, and is pierced by six $\frac{3}{16}$-in.-diameter holes equally spaced around a 1-in.-radius circle. The series of short sloping lines where the tube and plate join indicates that the tube and plate are welded together.

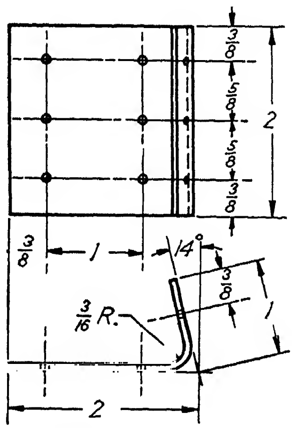


Fig. 5.20.—Clip—door jamb attaching.

5.5.3. Drawing 46, Clip—Door Jamb Attaching.—Draw the clip shown in Fig. 5.20 full size on a standard drawing form. In addition to the two views shown, draw a true view of the 1 in. long flange. The clip is made of $\frac{1}{16}$ in. thick sheet and has nine $\frac{3}{32}$-in.-diameter pilot holes that will be used on assembly to guide the drilling of full size holes, in which will be installed the attaching rivets or screws.

5.6. Curved Intersections.—To project an intersection of a curved and a straight surface a series of points are used. The intersection of the round tube with the flat end plate in Fig. 5.19 could be developed as shown in Fig. 5.21. An auxiliary view showing the round cross section of the tube in true view is used to locate a number of points on the circumference of the tube. The points are projected individually from the auxiliary view to the front view and to the true view. The distance, measured along the projection line, from the center line of the tube to each point in the true view, is obtained from the corresponding distance in the auxiliary view.

Point 1 in Fig. 5.21 is projected from the auxiliary view to the front view and thence to the true view. Point 1 is located A distance from the center of the tube in the auxiliary view, so

that the A distance is laid off from the center line of the true view locating point 1. A sufficient number of points should be selected to fair the curve smoothly. It will be noted that the points were selected symmetrically about both the vertical and the horizontal center lines of the auxiliary view. The same A dimension applies to four points on both sides of the center lines, and the horizontal line projecting point 1 also projects the corresponding point on the opposite side of the circle.

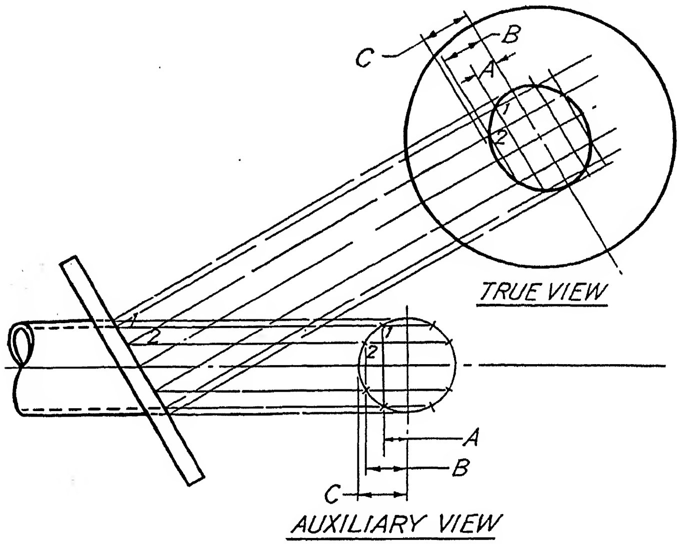


Fig. 5.21.—Intersection of a plane and a cylinder.

This intersection can be obtained by a simpler method by recognizing that any sloping cut of a tubular or cylindrical object produces an elliptical figure. The major axis of the ellipse is the distance across the tube at the slant cut, which may be projected to the true view from the front view. The minor axis of the ellipse is the diameter of the tube. Having the major and minor axes of the ellipse, the true shape of the figure may be developed by following the procedure described in Sec. 3.6.

Figure 5.22 shows the manner in which the intersection of a large and a small cylinder, meeting obliquely, may be developed. The main view shows the center lines of the two cylinders in the plane of the paper. Auxiliary views looking down the center line of each cylinder are then projected, and points around the

circumference of the smaller cylinder are located. These same points are then located on the true view of the larger cylinder, being found at equal distances from the corresponding center lines of the two auxiliary views, and are located in the main view by the crossing of the projection lines. It will be quite helpful if these points are projected one at a time. The points indicated by the intersections of projection lines are connected by a heavy line and all construction lines are then removed.

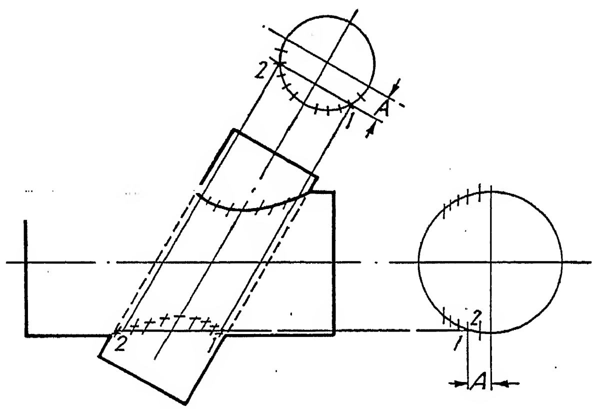


Fig. 5.22.—Intersection of two cylinders

In Fig. 5.22, the upper intersection of the two views has been developed and drawn in. The lower intersection is marked by the developed points. The smaller auxiliary or construction circle has been marked off in 15-deg. spaces to make the points symmetrical about both center lines of the circle. The projection of two points located A distance from the center line of the smaller cylinder is illustrated. The distance A, measured in the direction in which the upper view is projected, is first laid off on the auxiliary view of the large cylinder, locating points 1 and 2. Points 1 and 2 are then projected from the two auxiliary views to the main view where the projection lines intersect at the required points. The remainder of the points that determine the curved intersection are projected similarly. The projection lines shown in Fig. 5.22 are to assist in understanding the construction and are never drawn in, since they would only have to be erased from the finished drawing.

Exercises

5.6.1. Drawing 47, Intersections—Tubular.—Draw the views shown in Fig. 5.23 and complete all views shown. Auxiliary or construction circles should be drawn looking down the axes of each tube; these circles should be drawn lightly, using a 4H compass lead. It is suggested that the construction circles be divided into 15-, 30-, or 45-deg. sectors beginning at the center line of the projection for simplicity. Tube *A* is $1\frac{1}{2}$ in. in outside diameter, with a $\frac{1}{8}$ in. thick wall. Tubes *B* and *C* are 1 in. in outside diameter, with $\frac{1}{16}$ in. thick walls. Tube *D* is $\frac{5}{8}$ in. in outside diameter, with a $\frac{1}{16}$ in. thick wall. The lengths of tubes should be drawn four times the lengths scaled from Fig. 5.23.

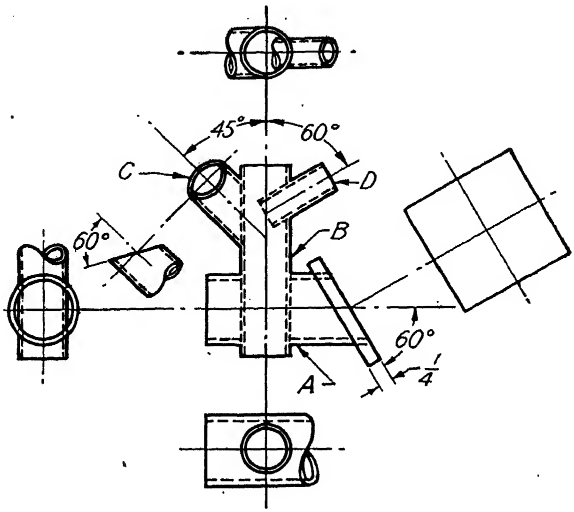


FIG. 5.23.—Intersections—tubular.

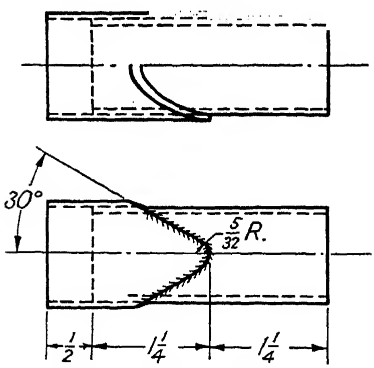


FIG. 5.24.—Weld—fish mouth.

5.6.2. Drawing 48, Weld—Fish Mouth.—Complete the top view of the welded tubes shown in Fig. 5.24. The outer tube is $1\frac{1}{8}$ in. in outside diameter, with $\frac{1}{16}$ in. wall thickness. The inner tube is 1 in. in outside diameter with $\frac{1}{16}$ in. wall thickness. The short slant lines along the 30-deg. cutoff of the outer tube indicate welding.

5.7. Summary.—Sections and auxiliary views are used in a drawing in order to clarify and explain details of the object that would not otherwise be clear. They are never complete pictures of the object and show only local details of its shape. Therefore, details of the object back of the plane of the cut in a section or back of the surface shown in an auxiliary view are usually omitted unless absolutely necessary to locate the view or the section with respect to the rest of the object. This is particularly essential to fast and simple drafting, for the contours behind the plane of the cut or the special surface are usually out of the plane of the paper and therefore difficult and complicated to depict. If shown, they would consume an inordinate amount of drafting time without making the drawing any clearer. In fact, the large number of lines required to show these details out of the plane of the paper would probably confuse the workman trying to interpret the drawing. The lines completely describing surfaces that are not in the plane of the paper in the main view are also often omitted if an auxiliary view or section clearly describes these areas of the object. Figure 5.25 shows a top view, a front view, and an auxiliary view. The hole on the left-hand side of the fitting is indicated by an ellipse in the top view, representing the intersection of the hole with the sloping surface. No attempt is made to show the bottom of the hole nor the sides of the hole entering the block in the top view, since the side view and the auxiliary view thoroughly describe the depth and diameter of the hole.

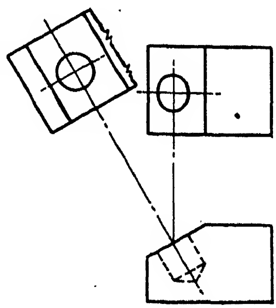


FIG. 5.25.—Omission of excess lines.

5.8. Problems.—The problems which follow are to be drawn full size on the standard drawing form. Unless otherwise noted, all fillets are $\frac{3}{16}$ in. in radius and all webs are $\frac{5}{32}$ in. thick. The views and sections to be shown should be carefully selected and arranged on the drawing. The dimensions given in the sketches are intended to fix the size of the object for the draftsman and are not necessarily in accordance with good drafting practice. Any dimensions not given may be scaled from the reduced size sketches.

5.8.1. Drawing 49, Fittings—Cross Sectioned.—Divide a standard drawing form into four rectangles and show the diametric view and the cross section of the objects sketched in Fig. 5.26. It will be noted that the plane

of the cross section falls on the center line of each object, although the break plane is not shown. The break plane should be indicated on the finished drawing and the cross section labeled as such.

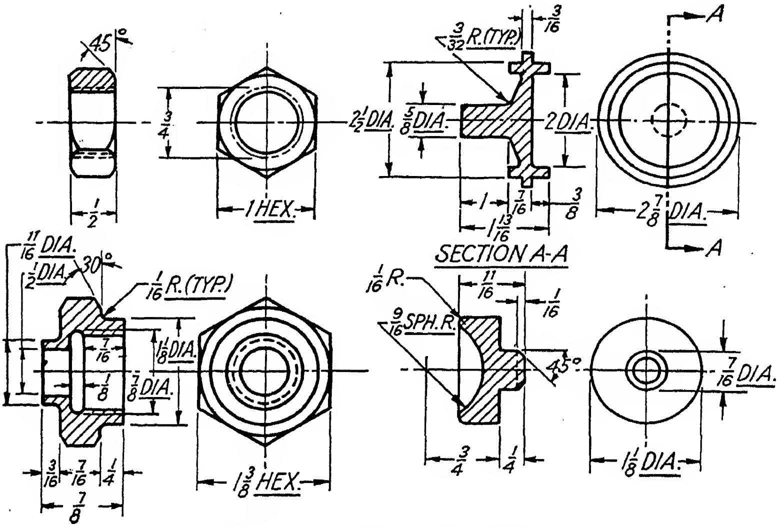


FIG. 5.26.—Fittings—cross sectioned.

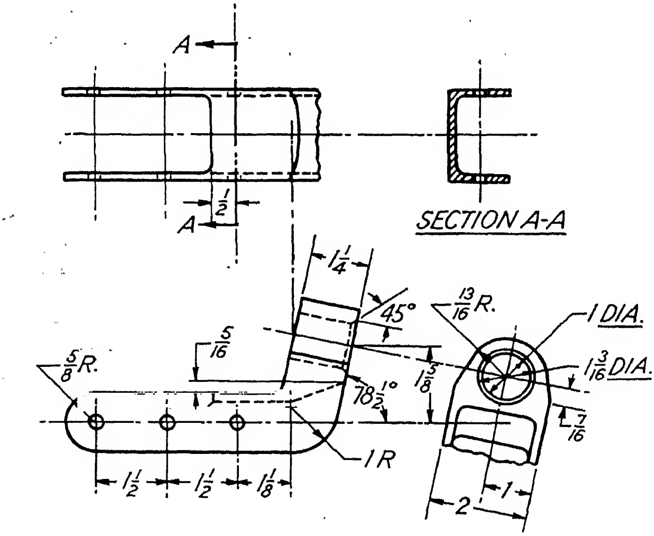


FIG. 5.27.—Socket—fixed gun forward mount.

5.8.2. Drawing 50, Socket—Fixed Gun Forward Mount.—Draw the socket shown in Fig. 5.27. The top view should be completed, but the true

view of the 1-in.-diameter hole is sufficiently complete as shown. The six holes in the flanges are ¼ in. diameter.

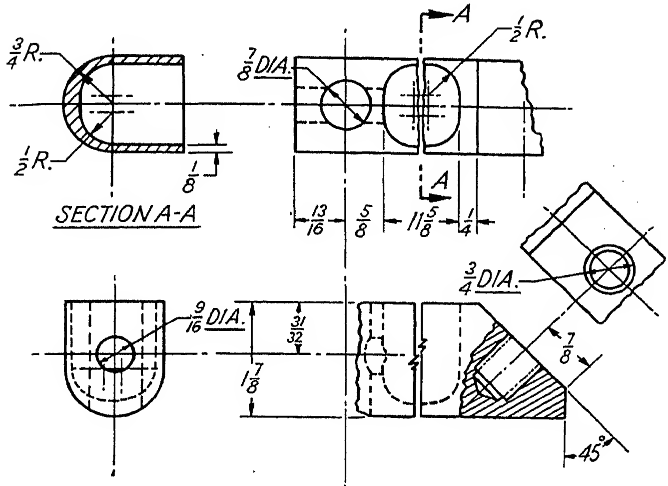


FIG. 5.28.—Fitting—engine mount longeron.

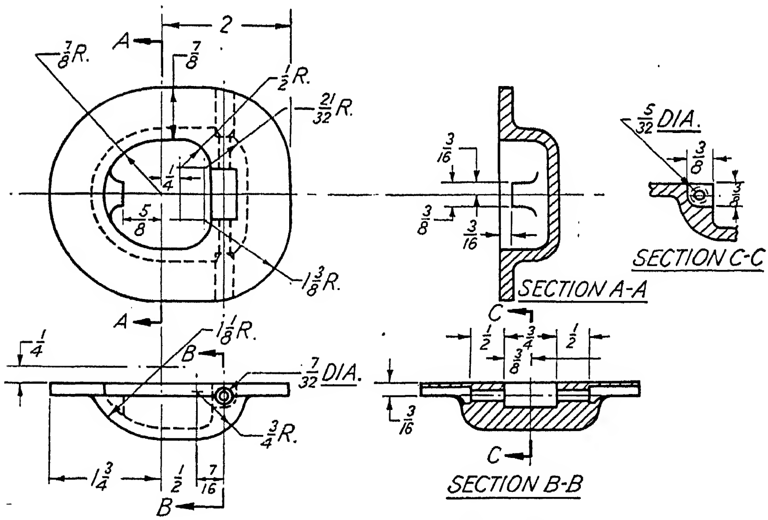


FIG. 5.29.—Base—tie down ring.

5.8.3. Drawing 51, Fitting—Engine Mount Longeron.—Draw the fitting shown in Fig. 5.28. The right-hand end of the top view, the left-hand end of the front view, and the lower right-hand end of the auxiliary view should be completed. The right-hand end of the front view has been broken out

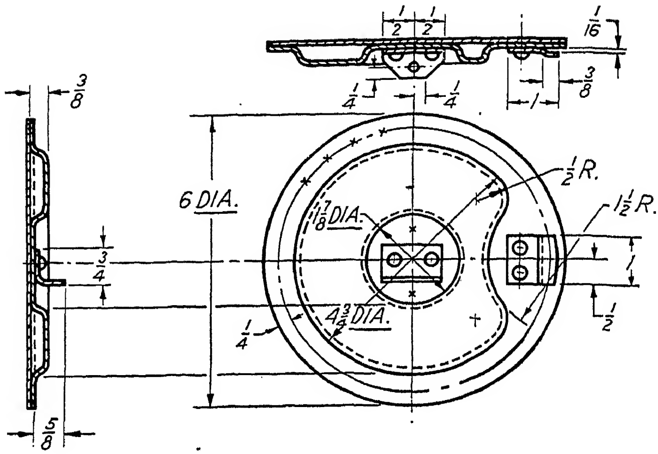


FIG. 5.30.—Door assembly—wing inspection.

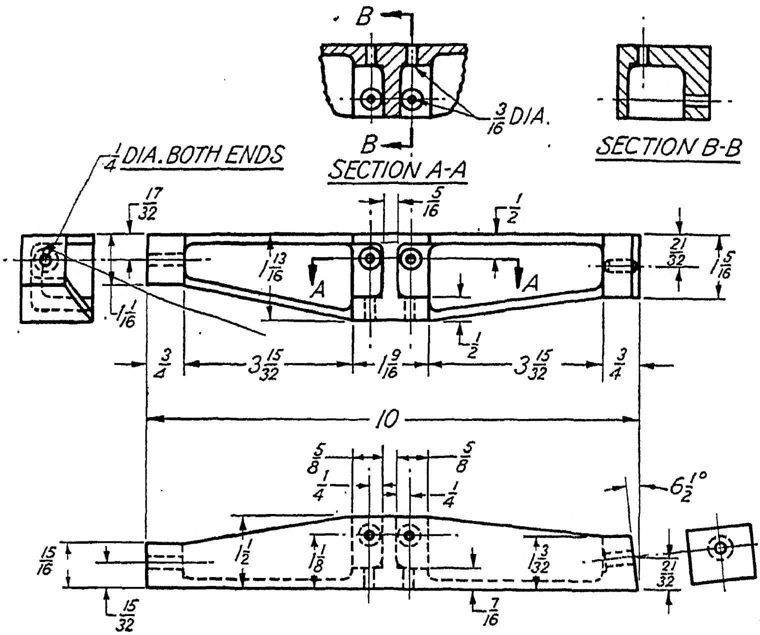


FIG. 5.31.—Bracket—bomb release support.

to show the details of the tapped hole. Due to the length of the fitting, the uniform cross section has been broken and shortened in Fig. 5.28 and should be so shown on the drawing.

5.8.4. Drawing 52, Base—Tie-down Ring.—Draw the ring shown in Fig. 5.29 full size. The sections may be rearranged or different sections may be selected.

5.8.5. Drawing 53, Door Assem.—Wing Inspection.—Draw the view and the sections shown in Fig. 5.30. The clips are attached with ⅛-in.-diameter rivets, which are located ¼ in. from the edges of the clips, the rivet heads being represented by arcs or circles of ⅛ in. radius. All sheets are 1/16 in. thick, and all bends are 3/16 in. in radius. The crosses on the center ine just inside the outline of the door represent the location of welds which

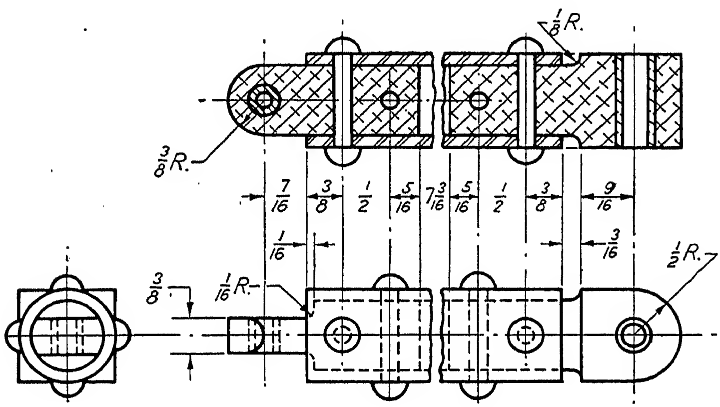


FIG. 5.32.—Rod assem.—elevator push.

join the two main sheets; the welds are spaced approximately ½ in. apart. The sections are taken at the horizontal and vertical center lines of the door.

5.8.6. Drawing 54, Bracket—Bomb Release Support.—Draw the bracket shown in Fig. 5.31. All undimensioned webs are 3/16 in. thick, and all fillets are 3/16 in. in radius. The six holes are for attaching bolts, and in order to provide a flat surface for the boltheads or nuts, a circular area is machined around each hole, removing the fillet radius. The machined area is 7/16 in. in diameter for the 3/16-in. holes and 9/16 in. in diameter for the ¼-in. holes.

5.8.7. Drawing 55, Rod Assem.—Elevator Push.—Draw the views and sections shown in Fig. 5.32 full size. Of what materials are the different parts of the rod composed? The attaching rivets are all 3/16 in. in diameter in the shank, and the heads are represented by an arc or circle of 3/16 in. radius. The bushings in the end holes are of 1/16 in. wall thickness; the hole in the left-hand end of the assembly is 3/16 in. in diameter, the hole in the right-hand end of the assembly is ¼ in. in diameter, and the tube is 1 in. in outside diameter, with a ⅛ in. thick wall. No cutting plane is indicated in the front view, but the section is assumed to be cut at the center line of the tube.

CHAPTER 6

DIMENSIONS

6.1. Reason for Dimensions.—Once the draftsman has produced a picture of the object by orthographic projection, consideration must be given to the manner in which the mechanic will use the picture to produce a physical object, exactly in accord with what the draftsman desired. The mechanic might measure the length and width and other dimensions of the drawing, but this operation would be highly troublesome and inaccurate. Most airplane manufacturers prohibit mechanics from scaling or measuring distances on a drawing, since these scaled distances are subject to many inaccuracies. First, the original drawing may be inaccurate or out of scale as much as $\frac{1}{32}$ in. when first drawn. Second, the original drawing paper will stretch or shrink with varying weather conditions, such as heat and humidity, or simply with age. Third, the mechanic works not with the original drawing but with a blueprint copy of the original drawing, which copy, during the blueprint process, is treated with liquids and heat. The blueprint copy very often shrinks or stretches, making the picture of the object on it different in size from the original drawing. Fourth, in measuring the distances on a blueprint, different mechanics would not always get exactly the same distances. Also, if a mechanic would have to measure the blueprint each time he started building one or more of the objects, the blueprint would be scaled over and over again with results usually differing from those originally intended for use. In some parts, distances are required to be held within a few thousandths of an inch variation. These accurate distances can be measured only with special measuring devices such as micrometer calipers. If the mechanic had to depend upon measuring inaccurate blueprints of an object for such accurate dimensions, the part would probably neither fit the airplane nor operate satisfactorily. Dimensions, therefore, are added to the drawing of the object to tell just exactly how

large the object shall be built in all its parts and its exact shape. The dimensions are further supplemented by notes which give the mechanic special instructions regarding operations to be performed, such as threading, tapping, reaming, drilling, etc.

6.2. Extension Lines.—The addition of dimensions to a drawing involves the use of two new kinds of lines: the extension line and the dimension line. Both types of lines are narrow black

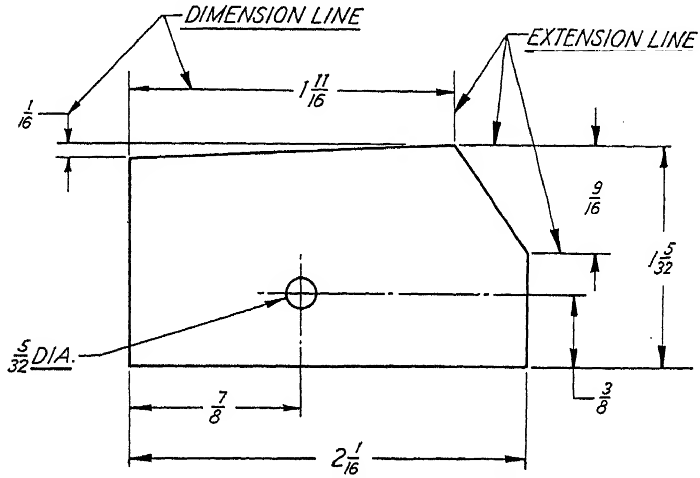


FIG. 6.1.—Extension and dimension lines.

lines of approximately the same width as a center line. Figure 6.1 illustrates extension and dimension lines, as used in drawing a small irregular-shaped plate. The extension line is an extension of an edge, a corner, or a surface of an object to which a dimension line may be drawn. The extension line should not touch the visible outline of the object but should begin approximately $1/32$ in. from the visible outline. Extension lines may be extended within the external outline of an object if they apply to a visible outline that begins and ends within the object. This extension line should begin $1/32$ in. from the internal visible outline from which it extends.

6.3. Dimension Lines.—Dimension lines are used to tell the mechanic the exact size of each part of an object. They extend between extension lines and/or center lines and are usually broken in the middle to permit printing in the numerical dimension. Care should be exercised to leave sufficient room in this

break so that the dimension will be at least $\frac{1}{16}$ in. away from the break in the dimension line. In a fractional dimension, the fraction bar is drawn in line with a horizontal dimension line, with the figures sufficiently separated from the fraction bar so that it cannot possibly be confused as part of the number. All numerical dimensions are lettered so that they may be read horizontally, regardless of whether the dimension line is horizontal or vertical. The figure 1 is always lettered at a slope in a vertical dimension line so that it cannot be misread as a section of the dimension line. The above instructions are all

FIG. 6.2.—Constructing the arrowhead.

necessary to make the dimensions easy to read and to prevent misinterpretation.

Dimension lines are *always* drawn perpendicular to the extension or center lines the separation of which they denote. The dimension line should just touch the extension line or center line on which it ends and should never pass through it nor stop short of it. Both ends of the dimension line are terminated by a long, slim arrow pointing toward the extension or center line to which the dimension applies. Roughly, the arrowhead should be one-third as wide as the length of the arrow. Arrowheads may be short for very short dimension lines but should be kept as uniform as possible for all ordinary dimensions. Figure 6.2 shows three steps that may be used in constructing arrows. The curved line forming the butt of the arrowhead is drawn first, then the concave lines forming the sides, and, last, the arrow is filled in solidly, all lines being drawn freehand. The dimension line should protrude at least $\frac{1}{8}$ in. beyond the butt of the arrow, before the line is broken off to insert the dimension figure.

If the dimension is shorter than $\frac{7}{8}$ in., the dimension line cannot be applied as described above. Figure 6.1 shows three other ways of applying the dimension line to such short dimensions. The $\frac{9}{16}$ in. dimension is placed between the two extension lines, and short dimension lines are placed outside the

dimension space, with the arrows pointing toward the dimension figure. Care must be exercised that the dimension figures are kept well separated from the extension line. Another method is to draw an ordinary dimension line between the two lines to which it applies, leaving the former unbroken and carrying it outside, but ending the dimension line in a short horizontal line followed by the dimension. This method is used, for example, to fix the distance from the hole to the bottom edge of the object at 3/8 in. The short bar is always *horizontal*, regardless of whether the dimension line itself is horizontal, vertical, or oblique. For very short dimensions, such as the 1/16 in. slope dimension, the dimension lines are placed outside the dimension space with a short horizontal leader directed to the dimension figure.

6.4. Dimensioning Practice.—Since dimensions are placed on the drawing to assist the mechanic in building a part of an airplane, the draftsman should always choose and arrange dimensions on a drawing in such a fashion as to be most useful to the mechanic. The dimensions should indicate how to build the object rather than how the draftsman has proceeded with the drawing of the detailed object. In order to accomplish this objective, it is necessary that the draftsman be thoroughly familiar with basic fabricating processes. This is too extensive a subject to cover, but it is summarized very briefly in Chap. 8. The draftsman should avail himself of every opportunity to become familiar with the shop, the tools, and the manufacturing methods used in constructing airplane parts which he may have to draw. Lacking basic information, the draftsman should ask himself this question: "Could I build the part from this drawing with the dimensions shown, and will it perform the job for which it is designed?"

Dimensions are generally arranged in two directions at right angles to each other. Outlines and dimensions that appear to be perpendicular are always assumed to be at right angles to each other unless the angle between them is specifically noted as being more or less than 90 deg. by means of an angular dimension or offset dimensions. In aircraft drawings, dimensions always indicate the number of inches in whole numbers and in common or decimal fractions. Neither the abbreviation, "in.," nor the symbol, ("), is used to indicate inches. Very long dis-

break so that the dimension will be at least $\frac{1}{16}$ in. away from the break in the dimension line. In a fractional dimension, the fraction bar is drawn in line with a horizontal dimension line, with the figures sufficiently separated from the fraction bar so that it cannot possibly be confused as part of the number. All numerical dimensions are lettered so that they may be read horizontally, regardless of whether the dimension line is horizontal or vertical. The figure 1 is always lettered at a slope in a vertical dimension line so that it cannot be misread as a section of the dimension line. The above instructions are all

a. b. c.
FIG. 6.2.—Constructing the arrowhead.

necessary to make the dimensions easy to read and to prevent misinterpretation.

Dimension lines are *always* drawn perpendicular to the extension or center lines the separation of which they denote. The dimension line should just touch the extension line or center line on which it ends and should never pass through it nor stop short of it. Both ends of the dimension line are terminated by a long, slim arrow pointing toward the extension or center line to which the dimension applies. Roughly, the arrowhead should be one-third as wide as the length of the arrow. Arrowheads may be short for very short dimension lines but should be kept as uniform as possible for all ordinary dimensions. Figure 6.2 shows three steps that may be used in constructing arrows. The curved line forming the butt of the arrowhead is drawn first, then the concave lines forming the sides, and, last, the arrow is filled in solidly, all lines being drawn freehand. The dimension line should protrude at least $\frac{1}{8}$ in. beyond the butt of the arrow, before the line is broken off to insert the dimension figure.

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Dimensions are generally arranged in two directions at right angles to each other. Outlines and dimensions that appear to be perpendicular are always assumed to be at right angles to each other unless the angle between them is specifically noted as being more or less than 90 deg. by means of an angular dimension or offset dimensions. In aircraft drawings, dimensions always indicate the number of inches in whole numbers and in common or decimal fractions. Neither the abbreviation, "in.," nor the symbol, ("), is used to indicate inches. Very long dis-

tances are written as a certain number of inches rather than as feet and inches; thus a 63 in. dimension would always be lettered "63" and not "63 in." or "5 ft. 3 in." Dimension lines should be spaced at least ⅜ in. away from the visible outline of the object, and parallel dimension lines should be spaced no closer than 5/16 in. In a series of parallel dimensions, as shown in Fig. 6.3, the dimension lines are equally spaced and the numerical dimensions are staggered in order to prevent interference among them. Every effort should be made to arrange dimension and extension lines so that they do not cross each

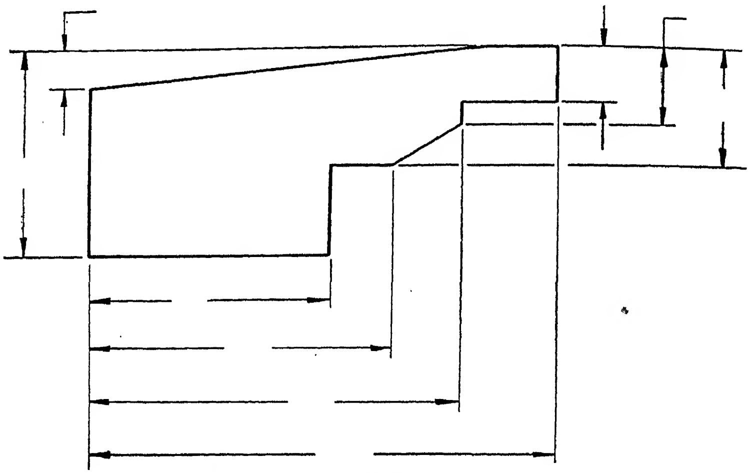


FIG. 6.3.—Arranging dimensions.

other. If, however, it is impossible to avoid crossing these lines, the extension lines should be broken where they cross dimension lines or other extension lines. If crossed dimension lines are unavoidable, they should *not* be broken, as illustrated in Fig. 6.3. Dimensions should never be crowded together as this would impare their legibility.

6.5. Locating Dimensions.—In general, dimensions should be placed on that view of the drawing which shows the contour in the plane of the paper or which describes the portion of the drawing dimensioned most clearly (see Fig. 6.4). Dimensions are usually the clearest when placed between two views of an object rather than on the outside of any view. Views should be spaced far enough apart so that sufficient room remains to place the

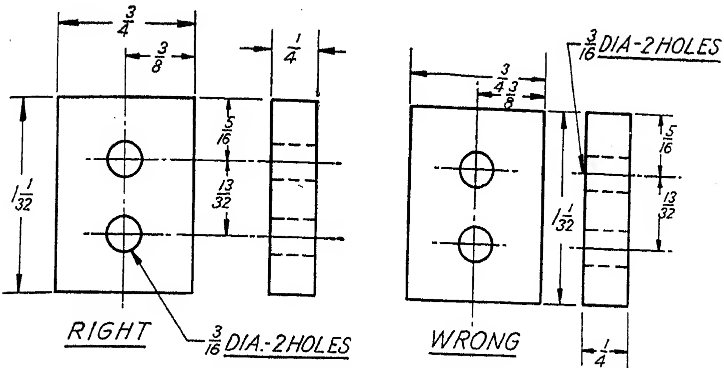


Fig. 6.4.—Locating dimensions.

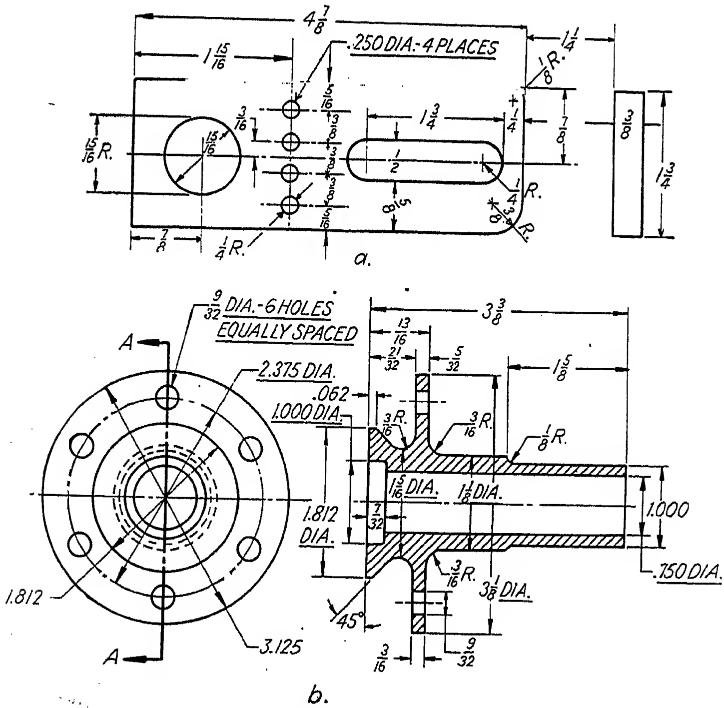


Fig. 6.5.—Exercise in dimensioning.

required dimensions between them without crowding. Dimensions should not be placed within the visible outline of a part unless an unusually long or complicated set of extension lines would be required to remove the dimension from inside the outline. Dimension lines should not touch the visible outline. Extension lines should be used to carry the visible outline to a convenient location for placing the dimension. An artificial center line should not be shown on any view of a drawing merely for convenience in dimensioning.

Exercise

6.5.1. Redraw the objects shown in Fig. 6.5, arranging the dimensions in accordance with the rules set forth above. Some of the dimensions conform while others do not.

6.6. Dimensioning Holes, Radii, and Angles.—Radii are always dimensioned by means of a figure followed by the letter *R* (see Fig. 6.6). Large radii are indicated by a dimension line

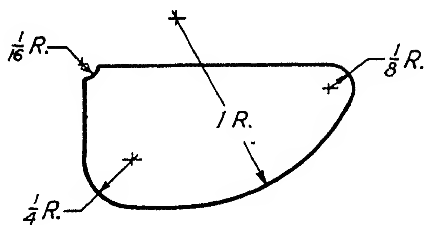


FIG. 6.6.—Dimensioning radii.

drawn from the center of the radius to some point on the circumference, preferably at a 45-deg. angle. The dimension line is broken near the middle, and the exact radius dimension is inserted therein. Only one arrowhead is used on a radius dimension, at that end of it which touches the circumference of the arc or the circle. Smaller radii are dimensioned by drawing one dimension line from the center of the radius to the arc or the circumference of the circle and by extending the dimension line outside the arc or the circumference, using a short horizontal leader line to the radius dimension. Extremely small radii may be dimensioned by an arrow pointing to either the convex or the concave side of the radius, with a short horizontal leader line connected to the dimension. It should be noted that, wherever

possible, the radius center is indicated by the intersection of short horizontal and vertical lines.

The size of large holes or circular bosses is indicated by a dimension line passing through the center of the hole or boss and

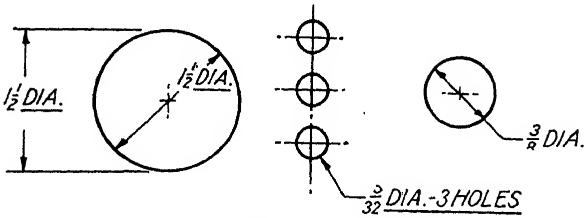


Fig. 6.7.—Dimensioning circles.

broken so that the figure expressing the number of inches may be inserted together with the abbreviation "Dia." The size may also be indicated by a dimension spaced between two parallel extension lines at any angle from the circumference of the circle. Smaller holes are dimensioned by a dimension line passing through the center of the circle, preferably at a 45-deg. angle, with arrowheads inside the circle; the dimension line is extended outside the circle, and a short horizontal leader is connected to the dimension. Very small holes are dimensioned by an external dimension line that touches the circumference of the circle (see Fig. 6.7).

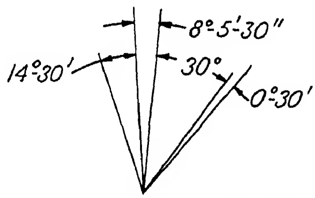


Fig. 6.8.—Dimensioning angles.

The angle between two lines is shown by a dimension line that is an arc of a circle whose center is the intersection of the two lines. The arrowheads touch the two lines, and the dimension line is broken in the center to permit the insertion of the number of degrees, minutes, and seconds. If room does not permit this method, the angular dimension line may be extended outside the angle to be dimensioned as shown in Fig. 6.8. It should be noted that the units of the angle, such as degrees, minutes, and seconds (°, ′, ″), are always indicated.

Note.—60 sec. = 1 min., 60 min. = 1 deg., and 360 deg. = a complete circle.

6.7. Choice of Dimensions.—The dimensioning of a part of an airplane must be sufficiently complete to ensure that the part

is built only one way and that each part will be identical to every other part built to the specified dimensions. No dimension may be omitted if it will permit two objects to be built from the same drawing with a variation in the omitted dimension. In Fig. 6.9, if the dimension indicated is not given a definite value, the mechanic may make the cut anywhere between nothing and 2 in. deep. Without this dimension, the object is not definite and, therefore, is not completely dimensioned. Dimensioning should be sufficiently complete so that the mechanic does not have to add or subtract in order to obtain a dimension required to build the object. From Fig. 6.10 only one physical object could be built to the dimensions shown, but the mechanic would have to add four separate dimensions to determine that a piece of sheet stock 3¾ in. long is required to fabricate the object.

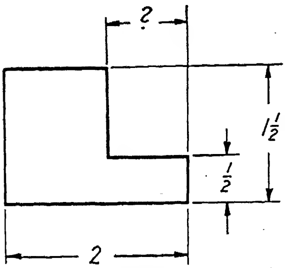


Fig. 6.9.—Omission of necessary dimensions.

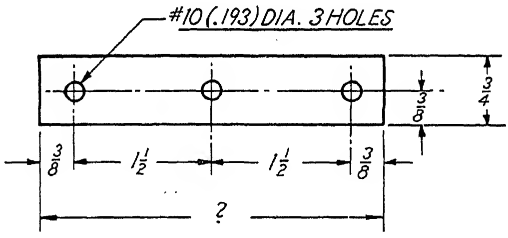


Fig. 6.10.—Omission of over-all dimension.

The two principles discussed above are emphasized in order to obtain sufficient dimensions on a drawing. However, excessive dimensioning confuses a drawing, obscures the outline of the described object, and is just as undesirable as insufficient dimensioning. Also, when changes to a drawing become necessary, it is very easy to change one dimension but to overlook a duplication of that dimension elsewhere on the drawing. Therefore, the distance between two points, two lines, two surfaces, or a combination of any two of the above, should be indicated only once on any drawing. Figure 6.11 contains several examples

of duplications. The student should determine each case of duplication and remove the less desirable dimension.

There are many devices for decreasing the number of dimensions actually used on a drawing, a few of which are listed below. The student can and should devise further means of decreasing the number of dimensions wherever such device can be employed

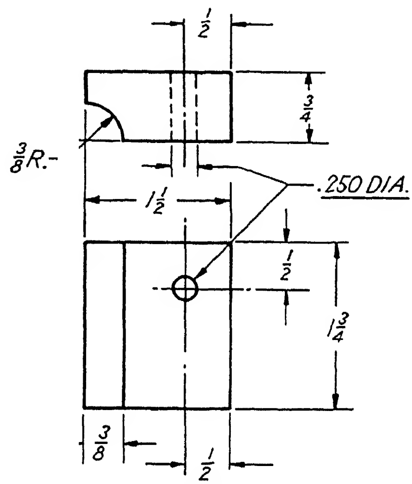


FIG. 6.11.—Duplication of dimensions.

without leading to confusion or impairing the clarity of the drawing. One of the most common devices for keeping an often repeated dimension from the body of the drawing is to incorporate that dimension in a general note. In making casting drawings, internal corners are never left square but are rounded out by filling the corners with cast material usually in the form of an arc, called a "fillet," the radius of which is usually common to all such corners. This fillet radius is given by a general note placed above the title block in this form: "Unless otherwise noted, all fillets 3/16 in. radius." Figure 6.12 shows a drawing of a typical casting which would require nine separate fillet radius dimensions on the body of the drawing had this general note not been used. In drawing riveted assemblies of sheet-metal parts, the center lines of the rivets are usually placed at twice the diameter of the rivet shank from the edge of any riveted sheet. Figure 6.13 shows such a typical riveted assembly, in which eight such rivet-edge-distance dimensions would be

required if placed on the body of the drawing. However, one general note, "Minimum rivet edge distance ¼," will elimi-

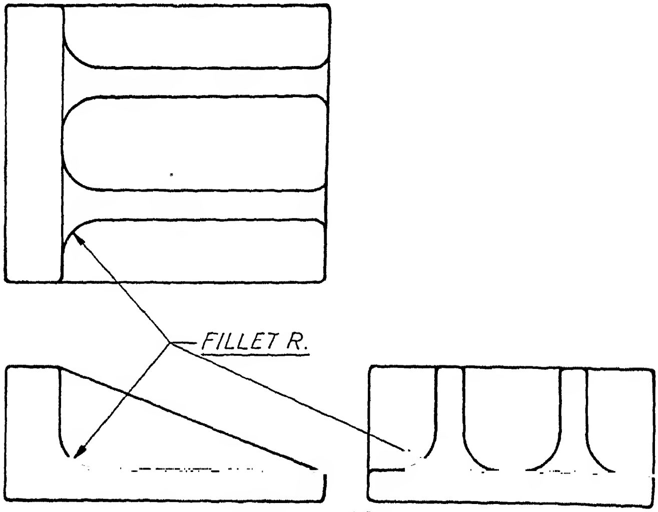


FIG. 6.12.—Fillets.

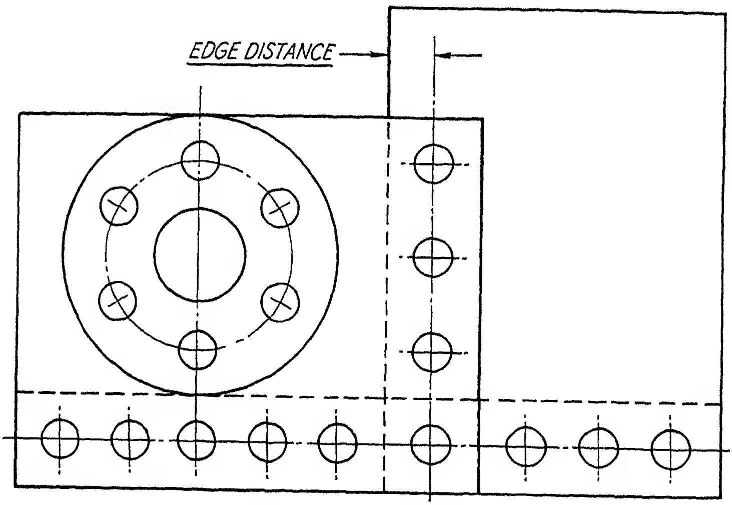


FIG. 6.13.—Rivet edge distance.

nate all such edge distance dimensions from the body of the drawing. Any dimension which would be frequently duplicated on the body of the drawing should be included in a general note.

In making bent sheet-metal parts, the bend radius is usually the same in all bends. Also, it is usually necessary to cut out metal in the corners where two different bends intersect. This metal is always cut out on a radius, since cracks tend to appear at sharp internal corners in sheet metal. Figure 6.14 shows such a typical bent sheet-metal part. If the bend radii and the bend relief radii were all dimensioned on the body of the drawing, 16 separate dimensions would be required on the body of the

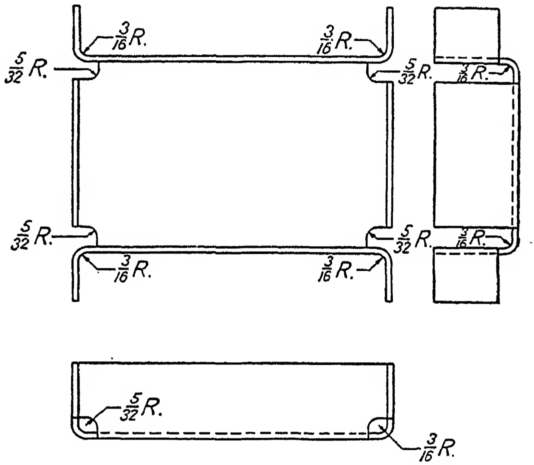


FIG. 6.14.—Bend radii and bend reliefs.

drawing. The same information could be given by these two general notes: "All bends $3/16R$; all bend reliefs $5/32R$." "Typ." (meaning "typical") is often placed after a dimension to indicate that that dimension applies to any other similar configuration on the drawing. In formulating these general notes, care should be taken that they are clear, concise, and not subject to any misinterpretation.

Holes on a drawing are often spaced uniformly. To prevent repetition of this spacing dimension, it is shown only once, followed by "etc.," which indicates that the dimension is repeated until the hole pattern stops or is radically changed. Instead of indicating the size at each hole of a particular size, the number of holes of that size is specified. If holes of several sizes occur in a single drawing, leader lines and arrows may be carried to each hole of a particular size. If there can be no misunderstanding

as to which holes are meant, a single leader line and arrow may be carried to only one of the holes. In Fig. 6.15, the dimension "⅜ Typ." indicates that the small holes around the edge are spaced ⅜ in. away from both the edge and the sides of the part. The "¼*R* (Typ.)" dimension applies to all four corners. The 14 small holes are not subject to confusion, and, therefore, only one leader line and arrow are carried to one of the holes. Of the four larger holes, two are reamed and two are drilled. Therefore, leader lines and arrows are carried from the drill note to both the

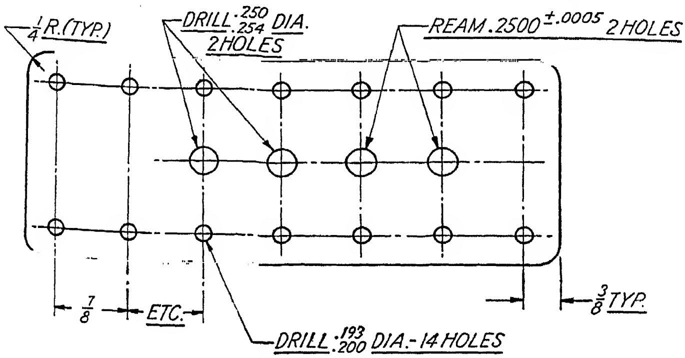


FIG. 6.15.—Avoiding dimension repetition.

drilled holes, and two other leader lines and arrows are carried from the ream note to the two reamed holes. The "⅞ etc." dimension indicates that each small hole is spaced ⅞ in. from the adjacent small hole on the horizontal center line. It should be noted that Fig. 6.15 is not cor[illegible] dimensioned; only those dimensions that illustrate h[illegible] ıplication are indicated. If a part [illegible] line, *i.e.*, the left-hand side of t[illegible] right-hand side of the part, th[illegible] the center line are shown, [illegible] indicated (see Fig. 6.16).

NOTE.—[illegible] dimensions (such as length an[illegible] ensions are already implied b[illegible] ver-all dimensions the mech[illegible] termine the over-all length[illegible] re given on all drawings.

6.8. Tolerances and Decimal Dimensions.—No matter how carefully an airplane part is built, some variation will occur between that part and any other part. A drawing must, therefore, specify how much variation is permissible from the stated dimensions while still permitting the part to function satisfactorily in the airplane. This variation from the specified dimensions is called "the tolerance of the dimension." Usually, aircraft drawing title blocks specify that fractional dimensions may have a tolerance of $\pm 1/32$ in. Decimal dimensions are

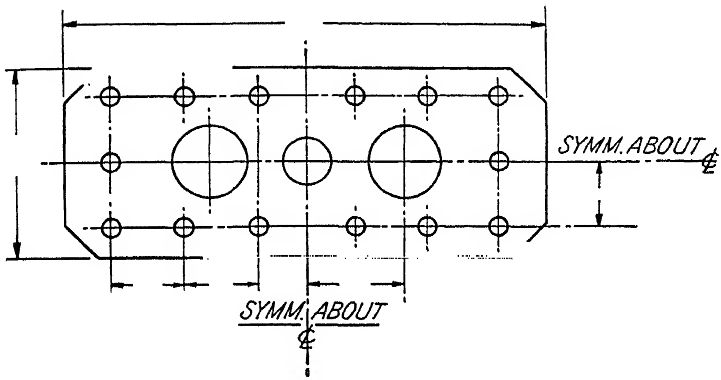


FIG. 6.16.—Dimensioning symmetrical parts.

usually permitted a tolerance of $\pm .010$ in. and angular dimensions, $\pm 1/2$ deg. Thus, the dimension $1\,9/16$ in. on a drawing would indicate that any dimension between $1\,17/32$ and $1\,19/32$ in. would be acceptable. A dimension of 1.500 in. would indicate that any dimension between 1.490 and 1.510 in. would be acceptable. An angular dimension of 43 deg. would indicate that if the angle lay between 42°30′ and 43°30′ the angular dimension would be acceptable. If tolerances greater or less than those specified above are required on a drawing, they must be specifically noted. Tolerances should always be made as generous as possible, since close tolerances require expensive tooling and will cause a larger proportion of the parts to be rejected and scrapped, thus increasing the cost of manufacture. In noting special tolerances, that one should be noted first which will permit the mechanic to perform additional work in order to approach the second tolerance. For holes, the lowest tolerance is given first, since a slightly small hole may be enlarged but a slightly large hole will

fall beyond the tolerance limits. In dimensioning cylinders, bosses, and closely held lengths of a part, the larger tolerance should be specified first, since material may be cut off the part to shorten it, but, once cut, it may not be added on. In turning down a cylinder, the mechanic will turn to the larger diameter; and should he cut off slightly too much material, the cylinder

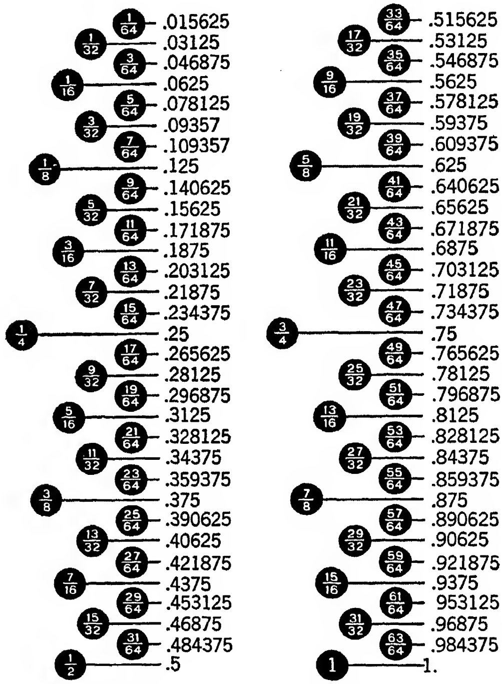


FIG. 6.17.—Decimal equivalents.

diameter will still lie between the high tolerance and the low tolerance. Special tolerances are usually written two ways. In one case, the nominal dimension is followed by the plus or minus tolerances: "1.000 ± .005 or 1.000 $\begin{matrix} + .000 \\ - .005 \end{matrix}$." In the other case, the high and low values of the dimension are given directly, thus: $\begin{matrix} 1.000 \\ .995 \end{matrix}$. In the first case, the tolerances are written in figures approximately 3/32 in. high. In the latter case, both figures are written the same size as the normal dimensions of the drawing.

The determination of tolerances required to make parts fit and operate properly is a subject beyond the scope of this text and properly belongs in the discussion of detailed drafting and layout work.

Decimal dimensions are always used to indicate dimensions that must be held very closely. The normal tolerance of $\pm .010$ in. is so small that it is practically impossible for the draftsman to make his drawing accurate to this tolerance, since .010 in.

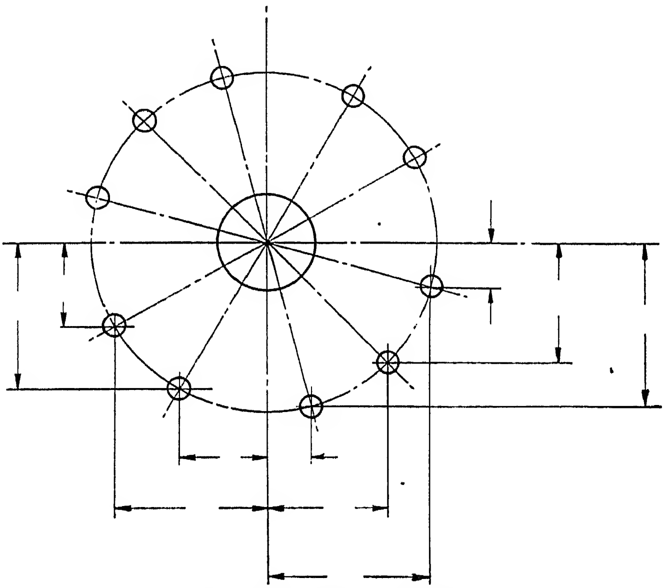


FIG. 6.18.—Offset dimensions.

is very nearly $\frac{1}{3}$ of $\frac{1}{32}$ in. A table for converting fractional dimensions to decimal dimensions is given in Fig. 6.17. The decimal equivalents given in this chart are exact and for fractions of $\frac{1}{32}$ in. are shown to five decimal places. However, the decimal dimensions used on aircraft drawings are carried out to only three decimal places, any figure beyond three decimal places being rounded off, except that where a four-place decimal tolerance is specified, the dimension is carried out to four places. The exact decimal equivalent of $\frac{3}{32}$ is .09375. This figure is rounded off to .094 when used on a drawing, since .09375 is closer to .094 than .093. Decimal dimensions should never be measured from a rough surface, such as a cast surface, since the

roughness of the surface may be greater than the ±.010 tolerance permitted by the dimension. A smooth machined surface or the center of a hole should usually be selected as the base from which decimal dimensions are carried.

6.9. Offset Dimensioning.—A point may be located in the plane of the drawing by denoting its distance from two lines at right angles to each other. The distances from the two lines are often referred to as "the offsets" of that point. Basically, all dimensioning is offsetting, but a certain type of dimensioning employs a strict offset method in which base lines at right angles

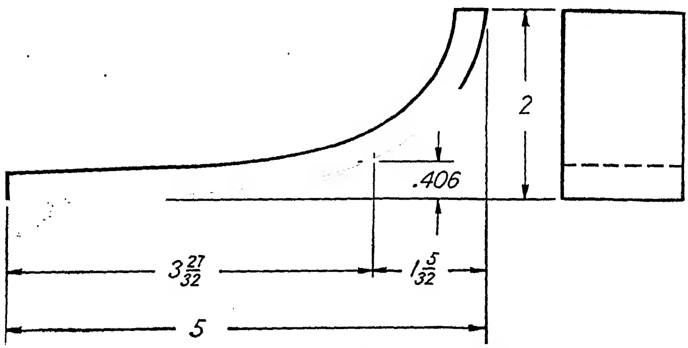


FIG. 6.19.—Dimensioning a contoured line.

to each other are established and a point or a series of points is located by means of offset dimensions from these two base lines. A typical example of such dimensioning is shown in Fig. 6.18. The holes shown actually lie on the circumference of a circle, but for some types of fabrication it is more convenient to locate the hole centers by horizontal and vertical dimensions from two perpendicular base lines. In Fig. 6.18, the base lines chosen were the horizontal and vertical center lines of the object. Offset dimensions are frequently used to locate a series of points through which a regular or irregular curved line may be drawn. Since a great deal of aircraft drawing work involves parts with irregular curved surfaces, such as the airfoil surface of a wing or a nacelle, offset dimensions are employed to a large extent. Figure 6.19 indicates the method of dimensioning an object which is contoured. The base lines are established as square edges of the part, and the offsets are taken to these base lines. When it is necessary to dimension an object which has curvature

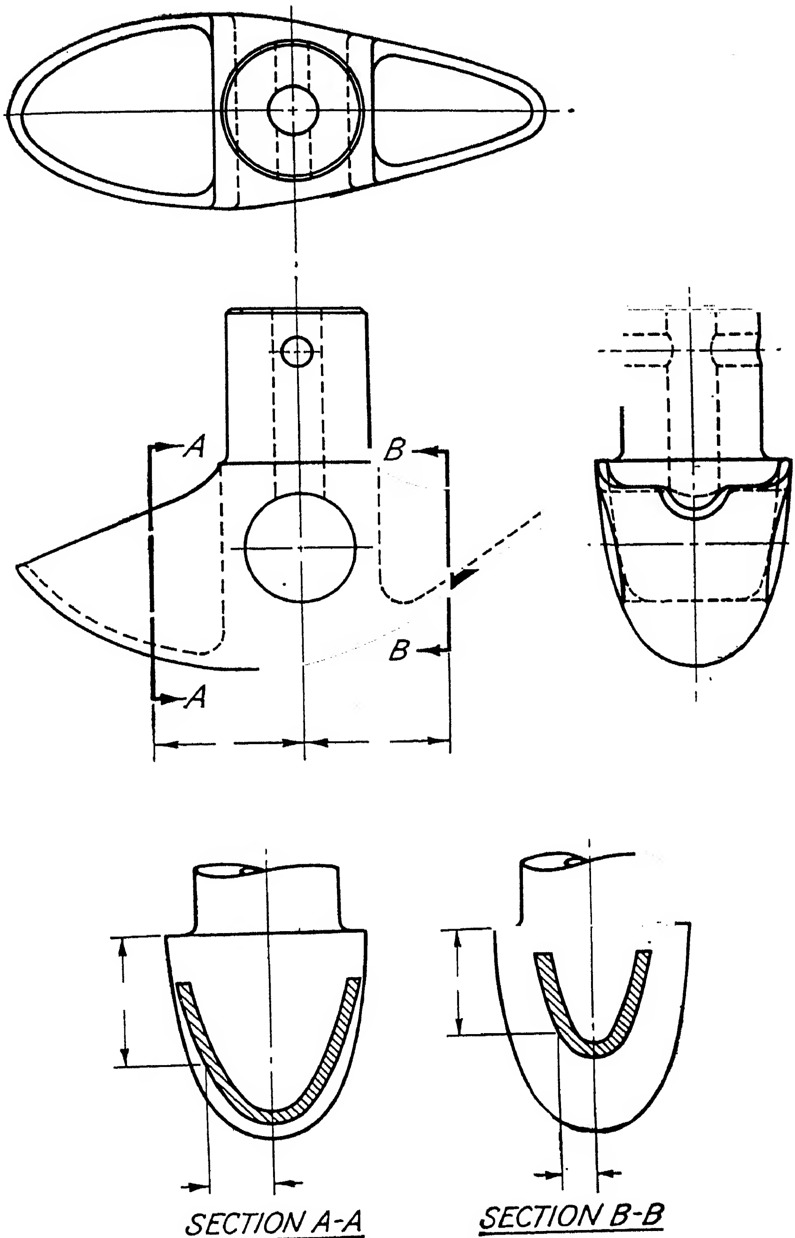


FIG. 6.20.—Dimensioning a contoured surface.

in two directions, such as a nacelle skin or a wing fillet, parallel cross sections are taken at intervals and the offsets of the curved surface are given for each curved section, as shown in Fig. 6.20. The term "fillet" used here has the same significance as when it is used in respect to castings, a fillet in airplane terminology being that which fills up. Thus, a wing-to-fuselage fillet would be a piece of structure that fills up the sharp irregular corners made by the intersection of the wing with the fuselage. This fillet is usually of thin sheet metal which fairs the lines of the fuselage smoothly into the lines of the wing, its contour being maintained by use of stiffeners or ribs inside the fillet.

If it is required to hold a sloping surface to very close angular tolerances, such as ± 1 min., it is more practical to locate the surface by decimal offset dimensions (see Fig. 6.21). The slope line or surface may be extended beyond the outline of the object, and the decimal offset may be given at some convenient distance, such as 10.000 in.

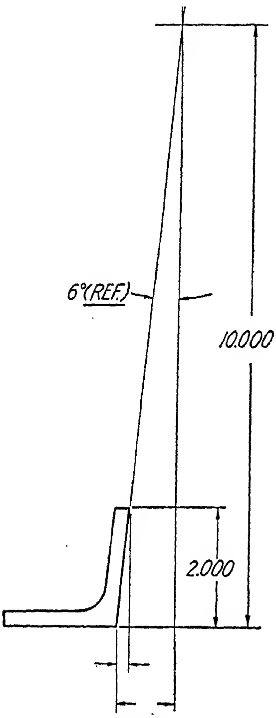


Fig. 6.21.—Offsets in dimensioning angles.

6.10. Problems.—Add dimensions and general dimension notes to the problems and exercises of Chaps. 4 and 5, following the principles set forth in this chapter. If the views have been arranged so close together that there is not sufficient room to dimension the drawing properly, the plate should be redrawn. All problems and exercises in succeeding chapters should be completely dimensioned.

CHAPTER 7

MATHEMATICS IN DRAWING

7.1. Introduction.—The application of geometry to drafting was discussed in Chap. 3 as an aid to the drawing work involved in orthographic projection and in descriptive geometry. Other branches of mathematics are necessary to, or expedite, the performing of the tasks upon which the actual drawing is based, particularly in the determination of dimensions. Such tasks involve calculating areas and volumes of parts upon which depend their strength and weight, calculating dimensions with closer accuracy than can be laid out and measured, and performing rapid calculations with a slide rule or calculator. The ability to handle work involving calculations enables the draftsman to adapt himself to wider and more complex fields of endeavor than does drafting skill alone, thus increasing his value to an engineering department and improving his chances for advancement.

Only those phases of mathematics which are most frequently used by the draftsman will be considered here, no attempt being made to follow the usual development of mathematics in which each new phase depends upon the principles of the previous phases. The student who is already thoroughly familiar with the mathematical principles discussed below should place particular emphasis on the application of these principles to drafting problems.

7.2. Significant Figures.—In mathematics, the value of a number, such as 1.305, is exact, no more or no less. In engineering work a number usually stands for a length or an angle and is subject to a permissible variation or tolerance due to human error and to the inaccuracy of measuring instruments. Thus, on a drawing the dimension 1.305 usually stands for 1.305 plus or minus .010 in.; *i.e.*, 1.295 to 1.315 in. The numbers which a draftsman uses are accurate only to a certain degree. Therefore, when such numbers are used in a mathematical process, the answer obtained thereby is no more accurate than the least

accurate of the dimensions employed. In finding the area of a rectangle the sides of which have been scaled as $\frac{31}{32}$ and $1\frac{15}{16}$ in. to the nearest $\frac{1}{32}$ in., the dimensions could be converted to the decimals .96875 and 1.9375, producing a product of 1.876953125. Most of the digits in the nine decimal places express wasted effort, for the product, or the area of the rectangle, is accurate to no more than the nearest $\frac{1}{32}$ sq. in., or $1\frac{7}{8}$ sq. in. (1.875). In all mathematical processes much labor can be saved if the process is discontinued when the partial answer is no longer significant. One simplification of the above multiplication might have been achieved by rounding off the decimals .96875 and 1.9375 to .97 and 1.94 before performing the multiplication, since these decimals are quite as accurate as the original fractional measurements. Performing the multiplication produces the product 1.8818, which should be rounded off to 1.88 or $1\frac{7}{8}$, the same product as was obtained above.

Exercise

7.2.1. Obtain the following products or quotients to the nearest one thirty-second: $3\frac{1}{8} \times 2\frac{19}{32}$; $\frac{13}{16} \times 2\frac{1}{32}$; $10\frac{5}{8} \div 1\frac{5}{16}$; $2\frac{7}{8} \div 3\frac{1}{4}$.

A quick method of multiplying fractions which are close to whole numbers may be achieved by first converting them into the near whole numbers plus or minus the fraction, by multiplying, and by disregarding the meaningless partial product. To find the product of $4\frac{3}{32} \times 1\frac{15}{16}$, the numbers are written $(4 + \frac{3}{32}) \times (2 - \frac{1}{16})$. This product is found to be the sum of the products of the first and third terms, first and fourth terms, second and third terms, and second and fourth terms:

$$\begin{aligned}&(4 \times 2) + [4 \times (-\tfrac{1}{16})] + (\tfrac{3}{32} \times 2) + [\tfrac{3}{32} \times (-\tfrac{1}{16})]\\ &= 8 \quad - \quad \tfrac{4}{16} \quad + \quad \tfrac{6}{32} \quad - \quad \tfrac{3}{512}\end{aligned}$$

Since the fourth term of the sum is much less than $\frac{1}{32}$, it may be dropped, producing a product of $8 - \frac{4}{16} + \frac{3}{16} = 7\frac{15}{16}$. The last term, $\frac{3}{512}$, need not even have been evaluated, since it may be seen by inspection that $\frac{1}{16} \times \frac{3}{32}$ is smaller than $\frac{1}{32}$.

In drawings, dimensions are rarely given to greater accuracy than the nearest $\frac{1}{1000}$ in., since parts cannot be built or inspected to smaller tolerances, except by using very costly fabricating and inspection devices. Therefore, practically all decimal equivalents of true fractional dimensions are rounded off to the nearest

$\frac{1}{1000}$ in. For example, $\frac{5}{16}$ is written decimally by rounding off its exact decimal equivalent, .3125, to .313; $\frac{3}{32}$ is written by rounding off .09375 to .094; $\frac{9}{32}$ is written by rounding off .28125 to .281.

7.3. Areas and Volumes.—It is often necessary to calculate the areas and volumes of more or less regular figures in order to calculate stresses on parts, to design parts which will withstand these stresses, and to determine the weight and the cost of parts. The following formulas are those most frequently used:

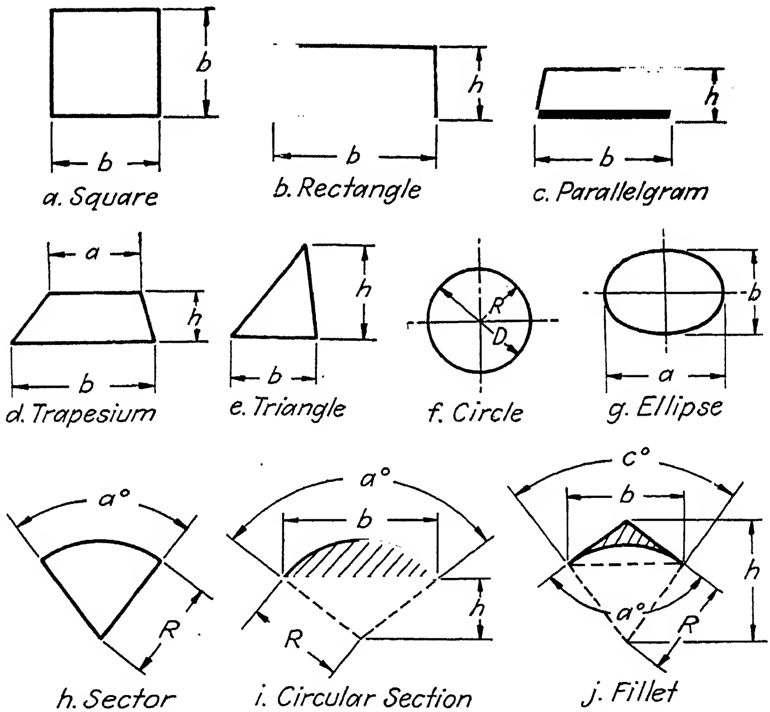


FIG. 7.1.—Plane geometric figures.

a. Square	$A = b \times b = b^2$
b. Rectangle	$A = b \times h$
c. Parallelogram	$A = b \times h$
d. Trapezium	$A = \frac{1}{2}(a + b) \times h$
e. Triangle	$A = \frac{1}{2}b \times h$

f. Circle $A = 3.1416R^2$
$A = .7854D^2$

g. Ellipse $A = .7854 \times a \times b$

h. Sector $A = 3.1416R^2 \times a/360$

i. Area between an arc and its chord. This equals the area of the sector formed by the arc minus the area of the triangle formed by the chord and the two radii:

$$A = 3.1416R^2 \times \frac{a}{360} - \frac{1}{2}b \times h$$

NOTE.—The length of b and h are determined by the angle and the radius of the arc. Determining their exact values is a function of trigonometry which will be discussed later. For the present, solution of this area would depend upon scaling b and h.

j. Fillet. The area formed by two intersecting lines and the radius tangent to them:

$$A = \frac{1}{2}h \times b - 3.1416R^2 \times \frac{c}{360}$$

NOTE.—Since the radii of the arc to the points of tangency form 90-deg. angles with the tangents, the angle c equals 180 deg. minus angle a (the sum of all the angles in a four-sided figure equals 360 deg.). Distances h and b are fixed by trigonometric relations with R and angle a; these relations will be discussed later. For the present, solution of the area would depend upon scaling h and b. In most cases a equals 90 deg., and the four-sided figure is a square:

$$\begin{aligned} \tfrac{1}{2}b \times h &= R^2 \\ A &= R^2 - 3.1416R^2 \times \tfrac{1}{4} \\ &= R^2 - .7854R^2 \\ &= .2146R^2 \end{aligned}$$

Volumes.—(See Fig. 7.2.) V = volume. Any figure of constant cross section with end surfaces parallel to each other has a volume equal to the cross-sectional area times the length of the figure measured perpendicular to the plane of the cross section. This rule holds true regardless of whether the cross section is a regular geometric figure or an irregular shape.

Example.—The volume of a broom handle 1 in. in diameter and 50 in. long = $50 \times .7854 \times 1 \times 1 = 39.27$ cu. in. For simplest calculations, the cross-sectional area should always be taken in a plane perpendicular to the length of the object.

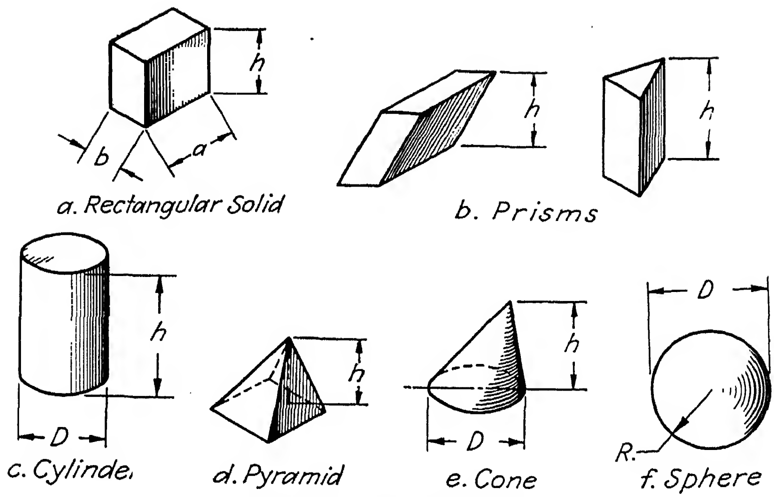


FIG. 7.2.—Geometric solids.

a. Rectangular solid. All intersecting planes are at right angles to each other:

$$V = a \times b \times h$$

Cube. This is a rectangular solid in which $a = b = h$:

$$V = a^3$$

b. Prism. The constant cross section is a polygon:

$$V = \text{cross-sectional area} \times h$$

c. Cylinder. The constant cross section is a circle:

$$V = .7854D^2 \times h$$

d. Pyramid. The base is any polygon; the sides are planes connecting the sides of the polygon with a point.

$$V = \tfrac{1}{3} \times \text{area of the base} \times h$$

e. Cone. The base is a circle, the circumference of which is connected to a point by straight lines.

$$V = \tfrac{1}{3} \times .7854D^2 \times h$$

f. Sphere. A ball:

$$V = \tfrac{4}{3} \times 3.1416 \times R^3 = 4.1888R^3$$
$$V = \tfrac{1}{6} \times 3.1416 \times D^3 = .5236D^3$$

To find the area of a figure that is not a simple geometric shape, the first step is to divide the figure into simple geometric figures. The area of each simple geometric figure is calculated, and all such areas are added together to find the total area. In Fig. 7.3, the area is divided into (a) a rectangle 1 in. by $\frac{3}{32}$ in. and (b) a trapezium of $\frac{7}{8}$ in. height and with bases of $\frac{1}{8}$ and $\frac{1}{4}$ in. The area of the rectangle $= 1 \times \frac{3}{32} = \frac{3}{32}$ sq. in. The area of the trapezium $= \frac{1}{2} \times \frac{7}{8} \times (\frac{1}{8} + \frac{1}{4}) = \frac{21}{128}$ sq. in. The total area of the figure $= \frac{3}{32} + \frac{21}{128} = .26$ sq. in.

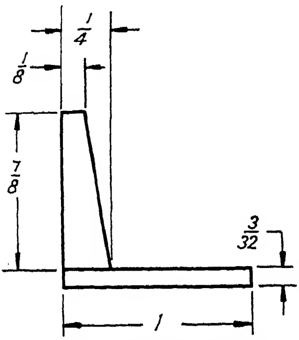


Fig. 7.3.—Combining areas.

In dividing a figure into simple geometric shapes, the area of a hole should be considered a negative area and therefore should be subtracted from the surrounding area. The cross-sectional area of the hollow cylinder or tube shown in Fig. 7.4 equals the

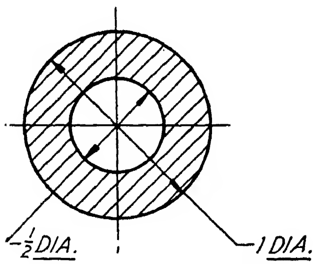


Fig. 7.4.—Area of a tube.

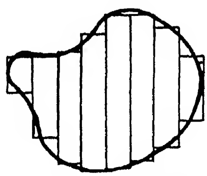


Fig. 7.5.—Area of an irregular figure.

area of the outer cylinder, $.7854 \times 1 \times 1$, minus the area of the hole, $.7854 \times \frac{1}{2} \times \frac{1}{2}$, or

$$A = .7854 - \frac{1}{4} \times .7854 = .589 \text{ sq. in.}$$

The area of a very irregularly shaped curved surface may be approximated graphically by dividing the figure into thin rectangular slices, which are equal in area to the corresponding slices of the curved surface, and obtaining the sum of the rectangular areas. In practice, a number of parallel lines are drawn equally spaced at some even distance such as $\frac{1}{8}$ in. Where these parallel lines cross the curved surface, perpendiculars are drawn

to form rectangles. These perpendiculars are located so that the area of the rectangle outside the curved surface equals the area of the curved surface outside the rectangle (see Fig. 7.5). The length of each rectangle is measured, its area calculated, and all the areas totaled. If the width of each rectangle is the same, the lengths of the rectangles may be added together and

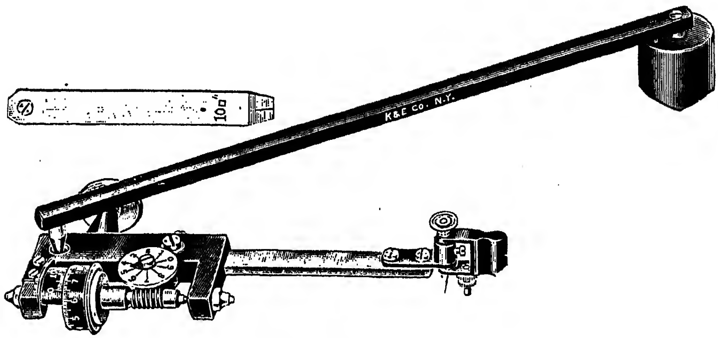


FIG. 7.6.—Polar planimeter.

the sum multiplied by the common width of the rectangles. An instrument called a "polar planimeter" will obtain the area of an irregular shaped figure quickly and accurately by tracing around the outline of the area with a stylus or point (see Fig. 7.6).

Exercises

7.3.1. Aluminum alloy weighs .1 lb. per cu. in. Calculate the weights of the extrusions whose cross sections are shown in Fig. 7.7 and whose lengths are noted below:

a. 33 in. long. This area may be divided into a rectangle $1\frac{5}{16}$ by $\frac{1}{16}$ in. and a 270-deg. sector of a $\frac{1}{16}$-in.-radius circle.

b. 17 in. long. This area may be divided into a rectangle 1 by $\frac{1}{16}$ in., a rectangle $1\frac{1}{16}$ by $\frac{1}{16}$ in., and a 90-deg. fillet of $\frac{3}{16}$ in. radius.

c. $\frac{7}{8}$ in. long.

d. 57 in. long.

e. 137 in. long.

f. $14\frac{3}{4}$ in. long.

g. 268 in. long.

h. $23\frac{11}{16}$ in. long (true ellipse).

7.3.2. What is the weight of 10 steel ball bearings $\frac{3}{8}$ in. in diameter? (Steel weighs approximately .28 lb. per cu. in.)

7.3.3. What is the weight of a steel torque tube $34\frac{1}{2}$ in. long, 1 in. in diameter, and with a wall thickness of $\frac{1}{16}$ in.?

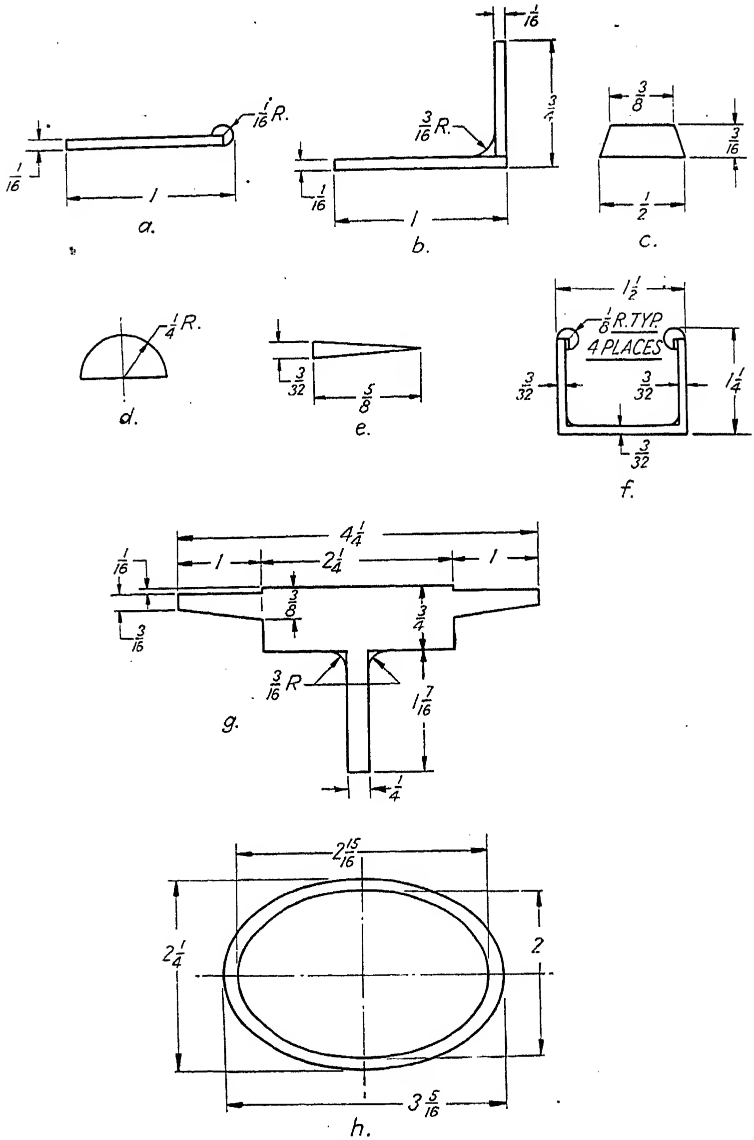


Fig. 7.7.—Extrusions.

HINT.—What is the area of the hole in the tube?

7.3.4. Trace carefully the streamlined strut, shown in Fig. 7.8, using an irregular curve. Determine its area approximately by rectangles, and calculate the weight of an aluminum alloy strut $33\frac{7}{8}$ in. long.

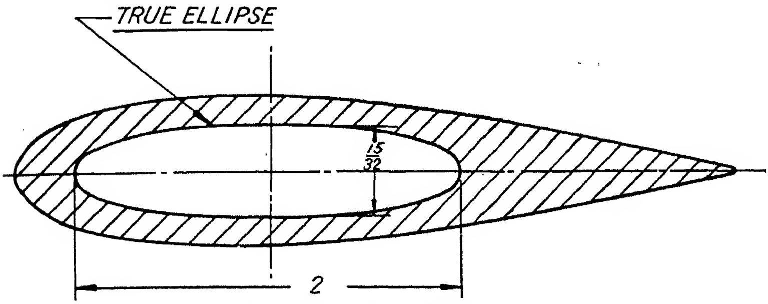


FIG. 7.8.—Streamlined strut.

7.4. Square Root.—The square root of a given number is defined as that number which when multiplied by itself equals the given number. The square root of 25 is 5. This is just the reverse of the square of a number, which is the product of the number multiplied by itself. The square of 5 (written 5^2) is 5×5, or 25. The square root of a number is written thus: $\sqrt{25} = 5$. The arithmetical process for extracting the square root of a number is given here to refresh the memory of the draftsman.

```
          2  3.  2  6  7
        √5'41.'36'20'00
          4
       43|1 41
         |1 29
       462|12 36
          | 9 24
      4646|3  12 2¦0
          |2  78 7¦6
       46527|33 4¦4 00
            |32 5¦6 89
                8¦7 11 00
```

The number is first pointed off into two digit places, beginning at the decimal point, both to the left and to the right. The largest square root in the number (or numbers) in the furthest left-hand place is written directly above it; thus, in the example, the largest square root in 5 is 2 and is written above the 5. This partial square root, 2, is squared and subtracted from the number in the left-hand place, leaving the remainder of 1. The

numbers in the next two places are brought down with the remainder, making it 141. The previously obtained partial square root, 2, is doubled to form the trial divisor, 4, which is written to the left of the new dividend, 141. The trial divisor 4 (really 40) is divided into the new dividend, 141, giving the result of 3, which is written above the second left-hand place of the original number. The number 3 is then added to the trial divisor, making the full divisor 43. The divisor 43 is multiplied by the partial square root, 3, giving the product 129, which is subtracted from the new dividend, 141, leaving a new remainder, 12, to which is added the number in the next place, 36, making a new dividend, 1236. The partial square root 23 is doubled to give a new trial divisor, 46 (really 460), which goes into 1236 two times, and the 2 is written above the 36 in the square root. The digit 2 is added to the divisor, making it 462, the divisor is multiplied by 2, and the product, 924, is subtracted from 1236, leaving a remainder of 312. The number 20 in the next place is brought down, and the process is repeated until the square root is obtained to the desired accuracy. It should be noted that the last three zeroes brought down are not significant figures, and therefore all calculations to the right of the vertical dotted line could have been omitted. The square root, 23.267, contains only five significant figures, while the original number, 541.362, contains six significant figures. The square root of a number contains as many significant figures as the number from which it is extracted; so the square root in the example would be accurate to one more figure, or 23.2672.

It will be noted that there is one place in the square root for every two places in the original number:

Number	5′41′36′20′00′00
Square Root	2 3 2 6 7 2

If each digit of a square root is placed below the two digits of the number from which it was extracted, the decimal point in the square root will fall directly below the decimal point in the original number:

Number	.00 06 25	2 07. 36	1 96 00.
Square Root	.0 2 5	1 4. 4	1 4 0.

The arrangement of the number and its square root in the extrac-

tion method previously illustrated permits the decimal point of the square root to be placed directly above the decimal point of the original number.

Exercise

7.4.1. Extract the square roots of 210.25, 22,500, and 2,000. How long is the side of a square sheet if its area is 18.0625 sq. in.?

7.5. Right Triangles.—The geometrical theorem of Pythagoras is used in the solution of many practical problems in aircraft drawing. It states that the square of the hypotenuse of a right triangle is equal to the sum of the squares of the two legs of that

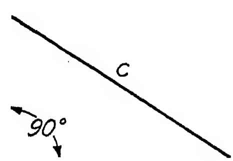


FIG. 7.9.—Right triangle.

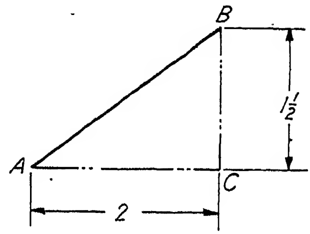


FIG. 7.10.—Offsets.

triangle. In Fig. 7.9, (side $c)^2$ = (side $a)^2$ + (side $b)^2$. Therefore,

$$c = \sqrt{a^2 + b^2}$$
$$b^2 = c^2 - a^2$$
$$b = \sqrt{c^2 - a^2}$$
$$a^2 = c^2 - b^2$$
$$a = \sqrt{c^2 - b^2}$$

If two legs of a right triangle are 9 and 12 in. long, respectively, the length of the hypotenuse equals:

$$\sqrt{9^2 + 12^2} = \sqrt{81 + 144} = \sqrt{225} = 15 \text{ in.}$$

Exercise

7.5.1. If the hypotenuse of a right triangle is 13 in. long and one leg is 5 in. long, how long is the other leg?

Dimensions on drawings are usually given as horizontal and vertical distances. In Fig. 7.10, point B is located from point A by dimensioning it 2 in. to the right and $1\frac{1}{2}$ in. up. The extension lines crossing at point C form a right triangle in which

one leg, AC, is 2 in. long and the other leg, CB, is 1½ in. long. The distance between points A and B, being the hypotenuse of the right triangle ABC, equals

$$\sqrt{2^2 + 1.5^2} = \sqrt{4 + 2.25} = \sqrt{6.25} = 2.5 \text{ in.}$$

NOTE.—To square or extract the square root of a common or mixed fraction, it is usually convenient to convert the fraction into a decimal fraction. The above problem could be handled entirely in improper fractions, since the root is finite, but in most cases fractions are awkward to handle. The fractional solution of the former example is as follows:

$$AB = \sqrt{2^2 + (1\tfrac{1}{2})^2} = \sqrt{2^2 + (\tfrac{3}{2})^2} = \sqrt{4 + \tfrac{9}{4}} = \sqrt{\tfrac{16}{4} + \tfrac{9}{4}}$$
$$= \sqrt{\tfrac{25}{4}} = \tfrac{5}{2} = 2\tfrac{1}{2}$$

Exercises

7.5.2. A point is 8 in. horizontally and 15 in. vertically from a given point. How far apart are the two points?

7.5.3. A pattern of 12 holes lies on the circumference of a 5-in.-radius circle (see Fig. 7.11). Four holes lie on the vertical and horizontal axes. The other eight holes are either 2.500 or 4.330 in. above or below the horizontal axis. Determine the offset dimensions A and B by calculation. Lay out the centers of the holes to scale, and check by measuring dimensions A and B.

HINT.—The vertical and horizontal dimensions are the legs of a right triangle whose hypotenuse is the 5 in. radius.

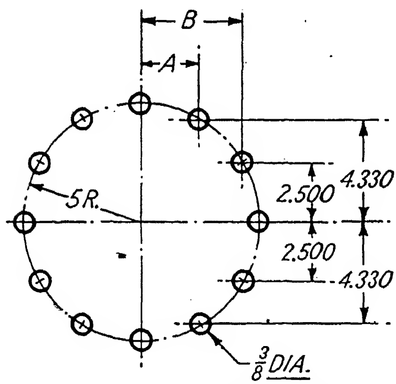


FIG. 7.11.—Calculating offsets.

The separation of two points is usually given by dimensions in three directions: sideways, x, fore and aft, y, and vertical, z. In aircraft work, the letters x, y and z are used to denote these three directional dimensions, all taken at right angles to each other. For example, in a room the separation of the two points could be considered as the diagonal running from one corner of the ceiling to the diagonally opposite corner of the floor, as represented by line AB in Fig. 7.12. The diagonal across the floor, BC, is the hypotenuse of a right triangle, BCD, of which x and y are the legs:

$$(BC)^2 = x^2 + y^2$$

The triangle ABC is also a right triangle in which AB is the hypotenuse and $AC(z)$ and BC are the legs:

$$(AB)^2 = z^2 + (BC)^2 = z^2 + x^2 + y^2$$
$$AB = \sqrt{z^2 + x^2 + y^2}$$

The true distance between any two points equals the square root of the sum of the squares of the rectangular offset's length, width, and height, or the squares of x, y, and z.

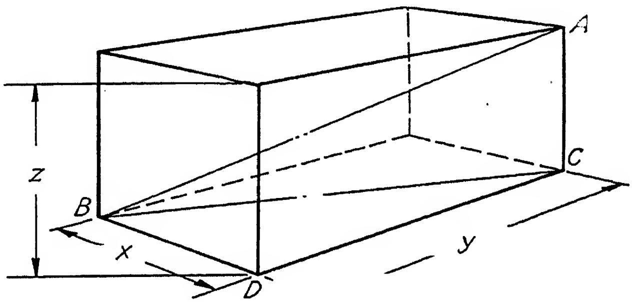


FIG. 7.12.—Relation between offsets and true length.

Example.—What is the true length of a brace extending between two points, one of which is 3 in. up, 12 in. aft, and 4 in. outboard (sideways) from the other?

Solution.—The true distance equals

$$\sqrt{x^2 + y^2 + z^2} = \sqrt{3^2 + 12^2 + 4^2} = \sqrt{9 + 144 + 16} = \sqrt{169} = 13 \text{ in.}$$

Exercises

7.5.4. A wing drag strut connects two bolt centers, one of which is 36 in. outboard, 32 in. forward, and 48 in. up from the other. How far apart are the bolt centers (the true length of the drag strut)?

7.5.5. An engine-mount-brace tube connects two points, one of which is 38 in. aft, 2 in. inboard, and 27 in. up from the second. What is the true length of the brace tube?

7.6. Trigonometry.—Trigonometry is one of the most used branches of mathematics in drafting. It enables the draftsman to determine the relations between angles of a right triangle and the lengths of the sides of the right triangle. As an example, in a 45-deg. right triangle the two perpendicular legs are equal to each other and the long side, or hypotenuse, is 1.414 times the length of either of the legs. Check this by actual measurement

of the 45-deg. triangle. In a 60-deg. triangle, the short leg is half the length of the hypotenuse. Check this on the 30–60-deg. triangle. These relations or trigonometric functions are designated as sines, cosines, tangents, cotangents, secants, and cosecants of an angle and form the basis of trigonometry. Being relations or ratios between the sides of a right triangle, trigonometric functions depend only upon the number of degrees in the angle of the right triangle, and, for a given angle, do not vary with the lengths of the sides of the triangle. The hypotenuse of a 30–60-deg. right triangle is always twice the shorter leg, regardless of whether the shorter leg is 1 in. or 1 mile long. Trigonometric functions always indicate that one side of a right triangle is a certain number of times as large as another side of the same triangle. That certain number of times may be more or less than 1.

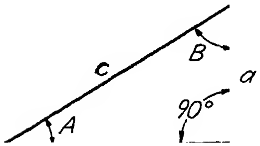


FIG. 7.13.—Trigonometric relations.

The relations of an angle to its trigonometric functions are explained in Table 7.1 (see Fig. 7.13).

TABLE 7.1.—TRIGONOMETRIC FUNCTIONS

Function	Abbreviations	Definition	Value from Fig. 7.13
Sine A..................	sin A	$\frac{\text{Side opposite of angle}}{\text{Hypotenuse}}$	$\frac{a}{c}$
Cosine A................	cos A	$\frac{\text{Side adjacent to angle}}{\text{Hypotenuse}}$	$\frac{b}{c}$
Tangent A...............	tan A	$\frac{\text{Side opposite of angle}}{\text{Side adjacent to angle}}$	$\frac{a}{b}$
Cotangent A.............	cot A	$\frac{\text{Side adjacent to angle}}{\text{Side opposite of angle}}$	$\frac{b}{a}$
Secant A................	sec A	$\frac{\text{Hypotenuse}}{\text{Side adjacent to angle}}$	$\frac{c}{b}$
Cosecant A..............	csc A	$\frac{\text{Hypotenuse}}{\text{Side opposite of angle}}$	$\frac{c}{a}$

The above relations of trigonometric functions to the appropriate sides of the triangle should be carefully and completely

committed to memory, particularly for sines, cosines, and tangents. Cotangents, secants, and cosecants are less frequently used, since they are the reciprocals of tangents, cosines, and sines:

$$\cot A = \frac{1}{\tan A} \qquad \sec A = \frac{1}{\cos A} \qquad \csc A$$

To become familiar with these functions, it is suggested that a number of right triangles be sketched in random positions, and the acute angles and sides be lettered. The sine, cosine, and tangent of the acute angles should be written in terms of the lettered sides until the student can identify the functions readily and without error, no matter what position the triangle may be in, and without having to refer to the definition of the functions.

Exercise

7.6.1. Referring to Fig. 7.13, write the sine, cosine, and tangent of angle B in terms of a, b, and c.

Tables of the numerical values of trigonometric functions of angles are available to varying degrees of accuracy and for varying steps of angles. There are tables which give the sine, cosine, and tangent of all angles from 0 to 90 deg. in steps of $\frac{1}{60}$ deg., or minutes, and give the function to seven or eight decimal places. For ordinary calculations, a table that gives the functions of angles in 1-deg. steps to four decimal places is sufficiently accurate. Since the values of the functions from a four-place table contain only four accurate digits, the answer obtained from a four-place table is accurate in only the four leftmost digits. If greater accuracy is required, more accurate tables must be used.

Table 7.2 gives the values of sine, tangent, cotangent, and cosine for angles from 0 to 90 deg. in 1-deg. steps to four decimal places. The first column contains angles from 0 to 45 deg., and the required function of each angle is found by reading across the page to the column which is headed at the top of the page as the respective function. The sine of 37 deg., .6018, is found in column 2 (headed "sine" at the top of the table) opposite 37° in column 1. The tangent of 25 deg., .4663, is found in the column headed "tangent" at the top of the page. The sixth column contains angles from 90 to 45 deg. The values of trigonometric functions of angles over 45 deg. are read from

TABLE 7.2.—TRIGONOMETRIC FUNCTIONS

Angle	Sine	Tangent	Cotangent		
0°	.0000	.0000	......	1.0000	90°
1°	.0175	.0175	57.290	.9998	89°
2°	.0349	.0349	28.636	.9994	88°
3°	.0523	.0524	19.081	.9986	87°
4°	.0698	.0699	14.301	.9976	86°
5°	.0872	.0875	11.430	.9962	85°
6°	.1045	.1051	9.5144	.9945	84°
7°	.1219	.1228	8.1443	.9925	83°
8°	.1392	.1405	7.1154	.9903	82°
9°	.1564	.1584	6.3138	.9877	81°
10°	.1736	.1763	5.6713	.9848	80°
11°	.1908	.1944	5.1446	.9816	79°
12°	.2079	.2126	4.7046	.9781	78°
13°	.2250	.2309	4.3315	.9744	77°
14°	.2419	.2493	4.0108	.9703	76°
15°	.2588	.2679	3.7321	.9659	75°
16°	.2756	.2867	3.4874	.9613	74°
17°	.2924	.3057	3.2709	.9563	73°
18°	.3090	.3249	3.0777	.9511	72°
19°	.3256	.3443	2.9042	.9455	71°
20°	.3420	.3640	2.7475	.9397	70°
21°	.3584	.3839	2.6051	.9336	69°
22°	.3746	.4040	2.4751	.9272	68°
23°	.3907	.4245	2.3559	.9205	67°
24°	.4067	.4452	2.2460	.9135	66°
25°	.4226	.4663	2.1445	.9063	65°
26°	.4384	.4877	2.0503	.8988	64°
27°	.4540	.5095	1.9626	.8910	63°
28°	.4695	.5317	1.8807	.8829	62°
29°	.4848	.5543	1.8040	.8746	61°
30°	.5000	.5774	1.7321	.8660	60°
31°	.5150	.6009	1.6643	.8572	59°
32°	.5299	.6249	1.6003	.8480	58°
33°	.5446	.6494	1.5399	.8387	57°
34°	.5592	.6745	1.4826	.8290	56°
35°	.5736	.7002	1.4281	.8192	55°
36°	.5878	.7265	1.3764	.8090	54°
37°	.6018	.7536	1.3270	.7986	53°
38°	.6157	.7813	1.2799	.7880	52°
39°	.6293	.8098	1.2349	.7771	51°
40°	.6428	.8391	1.1918	.7660	50°
41°	.6561	.8693	1.1504	.7547	49°
42°	.6691	.9004	1.1106	.7431	48°
43°	.6820	.9325	1.0724	.7314	47°
44°	.6947	.9657	1.0355	.7193	46°
45°	.7071	1.0000	1.0000	.7071	45°
	Cosine	Cotangent	Tangent	Sine	

the columns indexed as cosine, cotangent, tangent, and sine at the bottom of the page. The value of cos 71 deg. is read opposite 71 deg., in column 2 as .3256.

Exercise

7.6.2. Find the values of the following trigonometric functions from Table 7.2:

a. cos 3 deg.	*d.* cot 46 deg.	*g.* cos 13 deg.
b. tan 29 deg.	*e.* tan 64 deg.	*h.* cot 35 deg.
c. sin 52 deg.	*f.* sin 77 deg.	*i.* tan 55 deg.

With the values obtained from the tables, lengths of sides of right triangles or acute angles may be found. Referring to Fig. 7.13, if $a = 1.312$ and $c = 2$, $\sin A = 1.312/2 = .656$. In the sine column .6561 is found opposite the angle of 41 deg. in the first column, making angle A equal to 41 deg. If $b = 2.813$ and $a = 1.500$, $\tan B = 2.813/1.500 = 1.875$. This value does not appear in the third column, but in the fourth column there is a value, 1.8807, which is very close to 1.875. Since tangents in the fourth column indicate angles over 45 deg., angle B is found at the right of 1.8807 as 62 deg.

Example.—To find side a, given side $b = 4$ in. and angle $A = 21$ deg.:

$$\frac{a}{4} = \tan 21^\circ$$

$$a = 4 \times \tan 21^\circ$$

From the tables, tan 21 deg. = .3839

$$a = 4 \times .3839 = 1.5356$$

This answer should be rounded off to 1.536 in. or $1^{17}\!/_{32}$ in.

To find side c in the above triangle:

$$\frac{4}{c} = \cos 21^\circ$$

$$4 = c \times \cos 21^\circ$$

$$\frac{4}{\cos 21^\circ} = c$$

From the table, cos 21 deg. = .9336

$$c = \frac{4}{.9336} = 4.263 \text{ in.}$$

Referring to Fig. 7.1*i*, if angle a = 58 deg. and R = ⅝ in., the distance h may be found by bisecting angle A. This bisector is parallel to h, is equal to it in length, bisects b, and forms a right triangle of which R is the hypotenuse, one angle is ½a or 29 deg., and the legs are h and ½b.

$$\frac{h}{R} = \cos\frac{1}{2}a$$

$$\frac{h}{5/8} = \cos 29°$$

$$h = 5/8 \times \cos 29° = 5/8 \times .8746 = .547 \text{ in.}$$

Exercises

7.6.3. Find the value of b in Fig. 7.1*i*, using R = in. and a = 58 deg.

7.6.4. Find the values of h and b in Fig. 7.1*j* if R = 1 and angle a = 108 deg.

HINT.—The line drawn from the center of the circle to the intersection of the tangents bisects angles a and c and is equal to h in length. Also, the tangent and its radius form a 90-deg. angle.

7.6.5. If a cable rises 31 deg. from a plane, how far above the plane will it be 13 in. along the cable from the point it crosses the plane; how far along the plane will a point directly below the 13-in. point be from the intersection point?

The values of trigonometric functions of an angle not given in the table may be found by simple calculations. The sine of 39½ deg., being halfway between sin 39 deg. and sin 40 deg., is obtained by the following calculation:

sin 40°	= .6428
sin 39°	= .6293
Difference	= .0135
½ difference	= .0068
sin 39°	= .6293
sin 39½°	= .6361

Sines and tangents increase as the angle increases. In finding the values of cosines and cotangents, which decrease as the angle increases, the fraction of the difference must be subtracted from the smaller angle.

Example.—Find the cosine of 62.3 deg.

cos 62°	=	.4695
cos 63°	=	.4540
Difference	=	.0155
cos 62°	=	.4695
$-.3 \times$ difference	=	$-.0047$
cos 62.3°	=	.4648

Angles of less than 1 deg. are often expressed in minutes and seconds rather than a fraction of a degree. A minute (′) is $\frac{1}{60}$ deg., and a second (″) is $\frac{1}{60}$ min. or $\frac{1}{3600}$ deg. An angle written thus, 10°15′49″, means 10 deg. plus $\frac{15}{60}$ deg. plus $\frac{49}{3600}$ deg. This same angle could be converted to a decimal number of degrees by converting the common fractions to decimal fractions.

Example.—Find tan 41°39′ from the table.

41°39′ $41\frac{39}{60}$	=	41.65°
tan 42°	=	.9004
tan 41°	=	.8693
Difference	=	.0311
.65 × difference	=	.0203
tan 41°	=	.8693
tan 41°39′	=	.8896

Exercises

7.6.6. Find the sine, cosine, and tangent of 3.7°, 63°45′, 34°28′, and 82°36′.

7.6.7. In Fig. 7.1*i*, find b, h, and the area between the arc and the chord if $R = 3$ in. and $a = 88°40'$.

7.6.8. The wings of an airplane slope upward from the fuselage toward the tip, the angle of the slope being called "the dihedral angle" of the wing. If the dihedral angle of a wing is 6°35′, how much will the wing rise in a horizontal distance of 40 in.? What distance along the wing dihedral angle corresponds to this horizontal distance of 40 in.?

7.6.9. The bolt holes in Fig. 7.11 are spaced 30 deg. apart. The offset dimensions and the radii, drawn from the center of the circle to the hole centers, form right triangles of which the 5 in. radius is the hypotenuse. Calculate the offsets by trigonometry, and compare with the values previously obtained.

7.6.10. Calculate the horizontal and vertical offsets of the centers of five holes equally spaced around the circumference of a $3\frac{1}{2}$-in.-radius circle.

Some trigonometric tables do not give the values of functions of angles greater than 45 deg., since these equal different functions of angles smaller than 45 deg.

$$\begin{aligned}\sin A &= \cos (90 - A)^\circ \\ \cos A &= \sin (90 - A)^\circ \\ \tan A &= \cot (90 - A)^\circ \\ \cot A &= \tan (90 - A)^\circ\end{aligned}$$

Thus,

$$\begin{aligned}\sin 69^\circ &= \cos 21^\circ \\ \cos 78^\circ &= \sin 12^\circ \\ \tan 46^\circ &= \cot 44^\circ \\ \cot 54^\circ &= \tan 36^\circ\end{aligned}$$

Although a right triangle may not have an angle greater than 90 deg., angles greater than 90 deg. have trigonometric functions

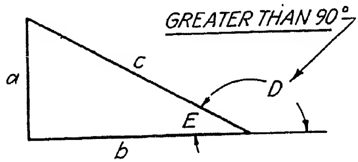


FIG. 7.14.—Trigonometric functions of angles greater than 90 deg.

of definite value. Trigonometric functions of angles between 90 and 180 deg. have the same numerical value as the functions of their supplements. The functions of angle D (see Fig. 7.14) may be written in terms of angle $E = 180 - D$.

$$\sin D = \frac{a}{c} = \sin E = \sin (180 - D)^\circ$$

$$\cos D = -\frac{b}{c} = -\cos E = -\cos (180 - D)^\circ$$

$$\tan D = -\frac{a}{b} = -\tan E = -\tan (180 - D)^\circ$$

$$\cot D = -\frac{b}{a} = -\cot E = -\cot (180 - D)^\circ$$

If angle $D = 146^\circ$

$$\sin D = \sin (180 - 146)^\circ = \sin 34^\circ = .5592$$
$$\cos D = -\cos (180 - 146)^\circ = -\cos 34^\circ = -.8290, \text{ etc.}$$

Exercise

7.6.11. Write the sine, cosine, tangent, and cotangent of 97°, 169°, 112°18′, and 151°45′.

In Chap. 3, it was stated that the size and shape of a triangle were determined if three sides, or two sides and the angle between them, or one side and any two angles were given. Triangles can be constructed from these dimensions, and the sides and angles not given may be determined by scaling them. Trigonometry provides a means of computing the unknown sides and angles with great accuracy by means of two formulas.

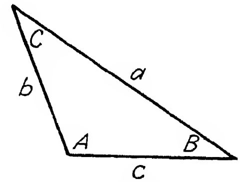


FIG. 7.15.—General triangle solution.

In Fig. 7.15 the angles of the triangle are labeled A, B, and C, and the sides opposite these angles are correspondingly labeled a, b, and c. The ratio of any side of a triangle to the sine of the opposite angle is the same for a given triangle:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Example. If $a = 2$ in., $b = 1$ in., and $B = 28$ deg., find c, A, and C.
Solution.

$$\frac{a}{\sin A} = \frac{b}{\sin B}$$

$$\frac{2}{\sin A} = \frac{1}{\sin 28°}$$

$$2 = \frac{\sin A}{\sin 28°}$$

$$2 \sin 28° = \sin A$$

$$2 \times .4695 = \sin A$$

$$\sin A = .9390$$

$$A = 69°53'$$

$$C = 180° - 69°53' - 28° = 82°07'$$

$$\frac{c}{\sin C} = \frac{b}{\sin B}$$

$$c = \frac{b \sin C}{\sin B} = \frac{1 \sin 82°07'}{\sin 28°} = \frac{1 \times .9906}{.4695} = 2.109 \text{ in.}$$

If, among the given side and angles of a triangle, one side and the angle opposite it are not included, the ratio of the side to the sine cannot be used. The following formulas though more complicated will help to obtain a solution:

$$c^2 = a^2 + b^2 - 2ab \cos C$$
$$a^2 = b^2 + c^2 - 2bc \cos A$$
$$b^2 = a^2 + c^2 - 2ac \cos B$$

Example.—If the three sides of a triangle are given as 4 in., 5 in., and 8 in., find the three angles.

Solution.—Let $a = 8$, $b = 5$, and $c = 4$.

$$b^2 = a^2 + c^2 - 2ac \cos B$$
$$5^2 = 8^2 + 4^2 - 2 \times 8 \times 4 \cos B$$
$$64 \cos B = 64 + 16 - 25 = 55$$
$$\cos B = 55/64 = .8594$$
$$B = 30°45'$$
$$a^2 = b^2 + c^2 - 2bc \cos A$$
$$64 = 25 + 16 - 2 \times 5 \times 4 \cos A$$
$$40 \cos A = 41 - 64 = -23$$
$$\cos A = -.575$$

The value of .575 corresponds to an angle of 54 deg. 54 min., but since $\cos A$ is negative,

$$A = 180° - 54°54' = 125°06'$$
$$C = 180° - B - A = 180° - 125°06' - 30°45' = 24°09'$$

Example.—In Fig. 7.15, given $c = 2$ in., $a = 3$ in., and angle $B = 53°$, find side b and angles A and C.

$$b^2 = a^2 + c^2 - 2ac \cos B$$
$$b^2 = 3^2 + 2^2 - 2 \times 3 \times 2 \cos 53°$$
$$b^2 = 9 + 4 - 12 \times .6018$$
$$b^2 = 5.7784$$
$$b = \sqrt{5.7784} = 2.404 \text{ in.}$$

Now using the ratios of sides to their sines,

$$\frac{b}{\sin B} = \frac{a}{\sin A}$$
$$\sin A = \frac{a \sin B}{b} = \frac{3 \sin 53}{2.404} = \frac{3 \times .7986}{2.404} = .9966$$
$$A = 85°15'$$
$$C = 180° - 85°15' - 53° = 41°45'$$

Exercises

7.6.12. In Fig. 7.15, given $c = 2\frac{1}{2}$ in., $a = 2$ in., and $b = 1\frac{1}{2}$ in., find angles A, B, and C.

7.6.13. In Fig. 7.15, given $b = 5$ in., $a = 4$ in., and angle $B = 72°27'$, find c, A, and C.

7.6.14. In Fig. 7.15, given $a = 3\frac{7}{8}$ in., angle $B = 22\frac{1}{2}$ deg., and angle $A = 57\frac{3}{4}$ deg, find C, b, and c.

7.6.15. Check the above calculations by laying the triangles out to scale and measuring the angles and sides calculated in Exercises 7.6.12, 7.6.13, and 7.6.14.

NOTE.—A scale layout check of calculations is an excellent method for discovering gross errors in calculation.

7.6.16. Two engine-mount-brace tubes are $21\frac{3}{8}$ and $28\frac{1}{8}$ in. long and intersect at the ends, forming a 47°15′ angle. What is the length of a third brace tube connecting the other ends of the first two tubes, and what angles are formed by the third tube with the other two tubes?

7.7. Slide Rule.—The slide rule is an instrument the draftsman finds particularly useful in making his calculations. Various types of slide rules may be obtained for different uses. Specialized rules are made for surveying, electrical engineering, and business calculations. Practically all rules, however, can be used for multiplying, dividing, extracting square roots, and for furnishing trigonometric functions, *i.e.*, finding sines, cosines, and tangents of angles and finding angles whose sines, cosines, and tangents are given. The arrangement, the number, and

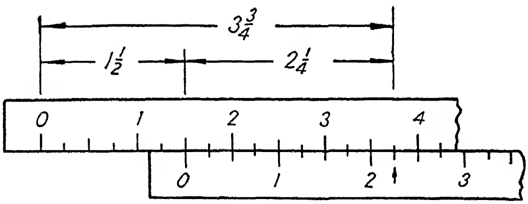


FIG. 7.16.—Adding and subtracting with scales.

the use of the scales of the slide rule vary among different models depending on the specialized operations for which they are designed. The best guide to the special operations and to the use of the extra scales may be found in the particular book of instructions which accompanies each rule. The following discussion is confined to the basic operations that may be accomplished on a simple slide rule as well as on the most complex rule. The Keuffel and Esser pocket slide rule (see Fig. 7.17) has been selected for purposes of illustration as a typical basic slide rule.

Two numbers may be added by using two 12-in. scales; $1\frac{1}{2}$ may be added to $2\frac{1}{4}$ by placing the zero mark of one scale on the $1\frac{1}{2}$-in. mark of the other scale, and noting that the $2\frac{1}{4}$-in. mark on the first scale lies on the $3\frac{3}{4}$-in. mark of the second scale, indicating that the sum of $1\frac{1}{2}$ and $2\frac{1}{4}$ is $3\frac{3}{4}$ (see Fig. 7.16). Similarly, two numbers may be subtracted by laying two scales together (see Fig. 7.16); $2\frac{1}{4}$ may be subtracted from $3\frac{3}{4}$ by

subtracting the length $2\frac{1}{4}$ from the length $3\frac{3}{4}$. The $2\frac{1}{4}$-in. mark on the lower scale is placed opposite the $3\frac{3}{4}$-in. mark on the upper scale, and the difference is read as the point on the upper scale in line with the zero mark on the lower scale, or $1\frac{1}{2}$. Multiplication and division are performed on a slide rule by addition and subtraction of lengths on two scales. A typical slide rule is illustrated in Fig. 7.17. It will be noticed that the spaces on the two scales of a slide rule are not marked off evenly, but are closer together as the figures become larger; the space between 1 and 2 at the left-hand end of the rule is much larger than the space between 9 and 1 (10) at the right-hand end of the rule. To multiply with a slide rule, the same procedure is followed as for addition with two 12-in. scales. In other words,

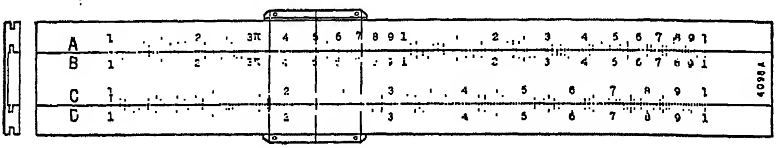


Fig. 7.17.—Slide rule.

the length on the slide-rule scale represented by one number is added to the length represented by the other number to be multiplied, and the length of the sum of these two numbers represents their product. To multiply 2 times 2, figure 1 on the *C* scale is placed directly in line with number 2 on the *D* scale. The slider is moved directly in line with figure 2 on the *C* scale and the product is read as 4 on the *D* scale. It should be noted that this is the graphical sum of the lengths on the scales representing 2 and 2. If the slider were moved to 4 on the *C* scale, the product would be read as 8 on the *D* scale.

If it is desired to multiply 2 times 6, it will be noted that 6 on the *C* scale is no longer opposite any number on the *D* scale, and this product may not be found with the first setting of the scale. If the product of two numbers is greater than 10, a different procedure must be used. Observing the scale, it will be noted that a 1 appears at both ends of the scale. If the product is greater than 10, such as in the multiplication of 6 times $4\frac{1}{2}$, the 1 at the right-hand end of the *C* scale should be placed even with 6 on the *D* scale and the slider moved even with the $4\frac{1}{2}$ mark on the *C* scale, giving an answer of 2.7.

However, 6 times $4\frac{1}{2}$ equals 27, and not 2.7. The slide rule does not determine the decimal point of the answer. In using the rule, an approximate product must be determined to locate the decimal point. To multiply 14.5×2.12, an approximate answer of 14×2 or 28 should first be determined mentally. The 1 mark on the *C* scale is then set at the 14.5 mark on the *D* scale, and the slider is moved to the 2.12 mark on the *C* scale, giving an answer of 30.6.

Division on a slide rule is accomplished by the reverse process of multiplication, or by subtracting the lengths corresponding to the numbers to be divided. If it is desired to divide 5 by $2\frac{1}{2}$, the slider is placed on the figure 5 on the *D* scale, and the *C* scale is moved until the $2\frac{1}{2}$ mark is exactly opposite the line on the slider and the 5 mark on the *D* scale. The quotient is then read as the point on the *D* scale, opposite the 1 on the *C* scale, or 2. It should be observed that in this calculation the slide rule is adjusted to the position for multiplying 2 times $2\frac{1}{2}$ which equals 5—which is another way of saying that 5 divided by $2\frac{1}{2}$ equals 2. In dividing, the slider is always placed on the dividend on the *D* scale, and the *C* scale is moved until the divisor appears on it opposite the dividend on the *D* scale. The quotient is then read as the point on the *D* scale opposite 1 or 10 on the *C* scale. If 3 is divided by 5; the number 5 on the *C* scale is placed opposite 3 on the *D* scale, and the quotient .6 is found on the *D* scale opposite 10 on the *C* scale. That the quotient is .6 and not 60 or 600 is determined mentally by dividing 3 by 5, which obviously gives less than 1. One common error in division is reading the quotient opposite the 1 on the *D* scale, or the scale upon which the dividend is set, rather than the 1 on the *C* scale, or the 1 upon which the divisor is set.

The *A* and *B* scales have the advantage of running from 1 to 100 instead of from 1 to 10, which enables direct multiplication of numbers whose products are greater than 10, such as 6 times 8. Number 1 on the *B* scale is placed opposite 6 on the *A* scale, and the product, 48, is read on the *A* scale opposite figure 8 on the *B* scale. To perform this same operation on the *C* and *D* scales, figure 10 on the *C* scale would be set opposite 8 on the *D* scale, and the product, 48, would be read opposite 6 on the *C* scale. The *C* and *D* scales, however, have the advantage of much greater accuracy, since the spaces between numbers are

twice as far apart as on the *A* and *B* scales, and the answer may be read more closely. For the same reason, a long slide rule is much more accurate than a short one. One type of slide rule in common use is the circular rule in which two disks are mounted on the same axis. The inner disk has a scale corresponding to the *D* scale, and the outer disk, a scale corresponding to the *C* scale. The procedure for multiplying and dividing on the circular rule is the same as has been explained for the straight slide rule.

Square root may be extracted on the slide rule by setting the slider on the number on the *A* scale and reading the square root on the *D* scale. If the slider is set on 9 on the *A* scale, the square root, 3, appears beneath the hairline of the slider on the *D* scale. If the slider is set at 90, however, the square root appears as 9.48. Care must be exercised in determining whether the figure should be set on the left-hand or the right-hand portion of the *A* scale. This is accomplished by pointing off two places at a time from the decimal point either to the left or to the right. If there are two figures in the left-hand space, the slider should be adjusted to the right-hand set of figures of the *A* scale. If only one figure appears in the furthest left-hand space, the slider should be set on the left-hand figures of the *A* scale. *Illustration:* $\sqrt{6'25'00}$. The slider is set on the left-hand figure 6 of the *A* scale, and the square root is found to be 250. In extracting $\sqrt{.00'16'81'}$, the slider is set on the right-hand figure 16 on the *A* scale, and the square root is .041. It will be noted from these two illustrations that for each place marked off in the square there will be one figure in the square root.

Sine and tangent scales are located on the reverse side of the sliding scale *B* and *C*. Sines of angles are found by placing the mark representing the desired angle on the *S* scale opposite the mark adjacent thereto on the back of the fixed scale and reading the sine of that angle on the *B* scale opposite the 100 mark on the *A* scale. The cosine of an angle may be found by determining the sine of its complement (90 deg. − the given angle); thus, cos 60 deg. equals sin (90 − 60 deg.), equals sin 30 deg., equals .500. Tangents may be obtained by placing the mark on the *T* scale representing the desired angle opposite the mark adjacent thereto on the fixed scale, and reading the

tangent on the C scale opposite the 10 mark on the D scale. It will be noted that the tangents include only angles of 45 deg. or less. The tangent of an angle greater than 45 deg. is found by obtaining the tangent of that angle subtracted from 90 deg., which equals the cotangent of the required angle, and dividing 1 by the cotangent. Thus, the tangent of 65 deg. is found by obtaining the tangent of 25 deg. (90 − 65 deg.), or .466, and

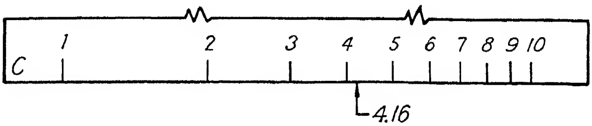


FIG. 7.18.—Primary divisions.

dividing 1 by .466, or 2.145. For more accurate work, trigonometric functions should be determined from the table rather than from the slide rule. To determine the angle whose sine is .89, set .89 on the B scale opposite 100 on the A scale, and the angle may be read on the S scale as approximately 63 deg. If the number were .089, the setting would be similar, except that the figure 8.9 would be used on the left-hand side of the B scale, and the angle would be found to be 5 deg. 5 min.

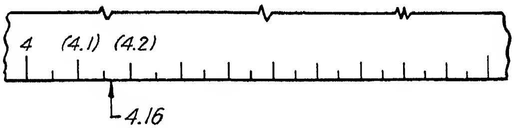


FIG. 7.19.—Secondary divisions.

One of the greatest sources of error in using the slide rule is misinterpreting the meaning of the marks, particularly near 1. The draftsman should make himself thoroughly familiar with the difference between 1.1, 1.01, and 1.001. Another skill which must be developed is that of estimating fractions of a space and converting them into numbers. To do this, familiarity must be gained in the meaning of the spaces on the rule. In a typical rule, each space from 1 to 2 represents .02 on the C or D scale; from 2 to 5, .05; and from 5 to 10, .1. To locate the number 4.16 on the C scale, the number will be between the fourth and fifth primary divisions of the scale, which are identified by digits (see Fig. 7.18). Figure 7.19 shows the area between the 4 and 5 marks enlarged, with 4.16 located between the 4.1 and

the 4.2 marks, which are not identified by digits. Figure 7.20 shows the area between 4.1 and 4.2 enlarged. The desired point 4.16 lies approximately 1/5 the distance between the 4.15 mark and the 4.20 mark.

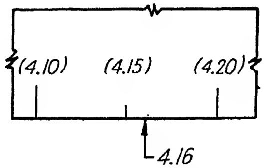


FIG. 7.20.—Estimated divisions.

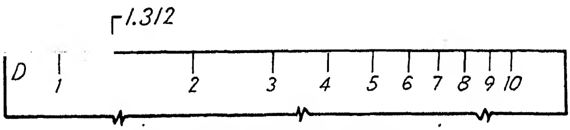


FIG. 7.21.—Primary divisions.

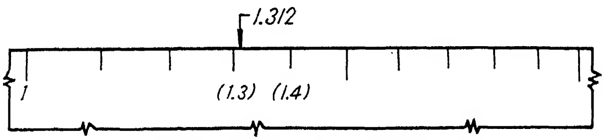


FIG. 7.22.—Secondary divisions.

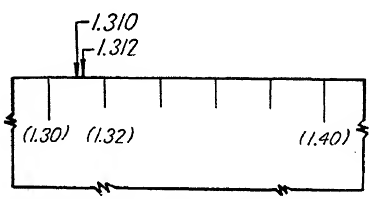


FIG. 7.23.—Estimated divisions.

To locate the number 1.312 on the *D* scale, the number will be between the first and second primary divisions (see Fig. 7.21). Figure 7.22 shows the area between the 1 and 2 marks enlarged. The desired point 1.312 lies between the 1.3 mark and the 1.4 mark, which area is shown enlarged in Fig. 7.23. The point 1.312 is 12/20 or 3/5 the distance between the 1.300 and the 1.320 marks to the right of the 1.300 mark. A more rapid and not less accurate method is to consider the 1.312 mark

just a shade to the right of 1.310, the mid-point between the 1.300 and the 1.320 mark.

Exercise

7.7.1. Adjust the slider to the following dimensions: *A* scale 2.75, 27.5, 6.7, 9.8, 1.2, 1.02. *D* scale 3.32, 7.75, .432, .927, .14, .104, 1.004.

The slide rule, although very sturdily constructed, is a precision built instrument and should be treated like a fine watch. Owing to use and to variations in temperature and humidity, the slide rule may get out of adjustment and it should be carefully and accurately readjusted. Most rules have set screws on each end of one of the fixed bars, which, when loosened, permit this bar to be moved to adjust friction on the sliding scale and alignment between the *A* scale and the *D* scale. A convenient method of accomplishing both these adjustments is to slip a very thin piece of paper between each end of the sliding scale and the *D* scale; then, with the 1 marks of the *A* and *B* scales exactly aligned, the loosened bar is adjusted until the 1 mark of the *D* scale is exactly aligned with the 1 mark of the *C* scale. The two fixed bars are then clamped together tightly and the set screws are tightened. The 10 marks of the *A* and *B* scales and of the *C* and *D* scales should then be checked for alignment, and the pieces of paper removed. The slide should then operate smoothly without sticking or slipping. Application of a little mild soap to the slides is helpful in obtaining free movement of the sliding bar without looseness. If a Duplex[1] rule—which has scales on both faces—is to be adjusted, after the first setting, as described above, the 1 and 10 marks on all scales on both sides of the rule are checked for alignment. Next, the glass slide is checked to make sure that the hairline passes through the 1 marks on the *A*, *B*, *C*, and *D* scales. If it does not, the set screws on the glass slide are loosened, the hairline is adjusted, and the set screws are tightened again. In the duplex-type rule, it is further necessary to adjust the hairlines on both sides of the slider so that they are not only square, but also pass through the 1 marks, concurrently on both faces of the slide rule. A magnifying glass will be found helpful in making these adjustments surely and accurately. The value of a slide rule to a draftsman increases as his familiarity with the instrument

[1] Trade-mark copyrighted by Keuffel & Esser.

develops, and such familiarity and usefulness of the slide rule can be developed only by constant practice.

7.8. Problems.

7.8.1. Calculate the cross-sectional areas of the extrusions shown in Fig. 7.24.

7.8.2. A spar-cap center line rises 24 in. and moves aft $9\frac{3}{4}$ in. in a horizontal distance of 167 in. Find the true length of the center line and the angle it makes with (*a*) the horizontal plane, looking aft, (*b*) the vertical

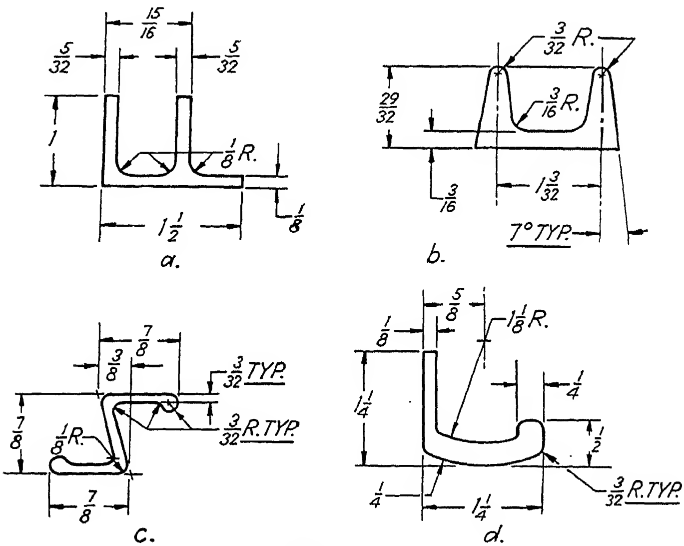


FIG. 7.24.—Extrusions.

plane located at right angles to the center line of the airplane, looking down, and (*c*) the line formed by the intersection of these two planes. It will be helpful to sketch the views looking aft and looking down before performing the calculations.

7.8.3. The center of a pulley-bracket guard is located on a $1\frac{25}{32}$ in. radius 19 deg. above the horizontal center line of the pulley. Determine the horizontal and vertical offsets of the guard center in $\frac{1}{1000}$ in.

7.8.4. Two intersecting cables form an angle of 36°13′. Find the distance between a point on one cable $56\frac{3}{16}$ in. away from the intersection, and a point on the other cable $42\frac{15}{16}$ in. away from the intersection.

7.8.5. Drawing 56, Fitting—Oil Tank Sump Adapter.—Draw the fitting shown in Fig. 7.25 full size on a standard drawing form. The offset dimension for the hole pattern should be calculated and included on the drawing. The 5-in.-diameter dimension should be marked "(ref.)" and the "equally

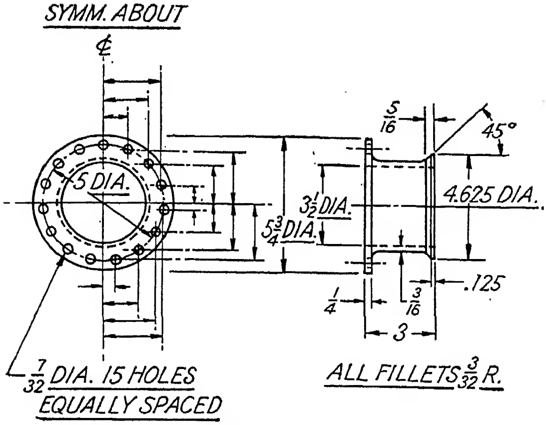


Fig. 7.25.—Fitting—oil tank sump adapter.

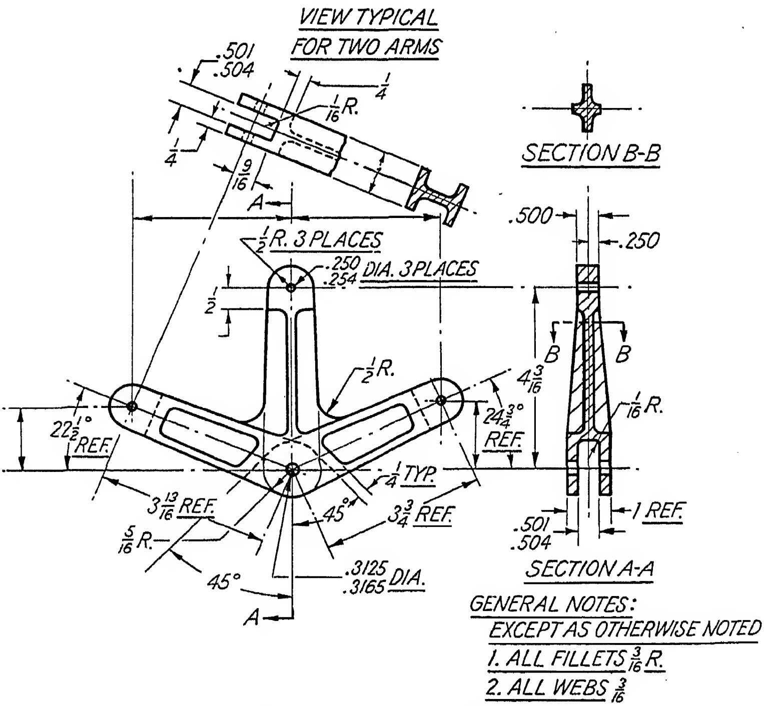


Fig. 7.26.—Crank—control cable bell.

spaced" note should be omitted, since the hole locations are fully specified by the dimensions shown.

7.8.6. Drawing 57, Crank—Control Cable Bell.—On a standard drawing form, draw the views and sections of the bell crank shown in Fig. 7.26 full size and in addition show a full top view. The offsets of the two ¼-in. holes in the arms at oblique angles should be calculated in decimals using the angles and the true distances between the holes as reference dimensions. Views and sections may be rearranged to conform to good drafting practice and to the best use of the drawing space.

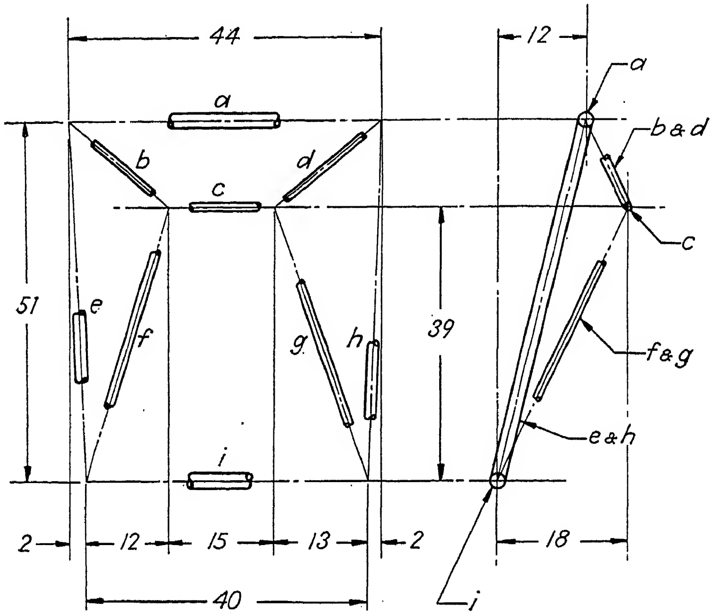


Fig. 7.27.—Truss—landing gear.

7.8.7. Figure 7.27 shows a diagrammatic representation of the tube center lines of a landing-gear truss in a side and an end view in which offset dimensions of the intersection points are given.

a. Find the length of each tube, using right triangles.

b. Determine the true angles between the tube center lines which form right triangles such as *h* and *i*, *b* and *c*, etc. Note that *a*, *c*, and *i* are parallel; what angles are equal or supplementary?

c. Determine the true angles between tubes which form oblique triangles such as *b*, *e*, and *f*, etc.

Note.—The slide rule will be useful in determining angles that are not an even number of degrees as well as their trigonometric functions.

d. Determine the cross-sectional area of tube *e*, which has an outside diameter of 2½ in. and a wall thickness of 5⁄32 in.; tube *c*, with an outside diameter of 1½ in. and a wall thickness of ⅛ in.

CHAPTER 8

REPRESENTING SPECIAL PARTS AND PROCESSES

8.1. Introduction.—There are a great number of different processes by which a shop produces the objects represented on engineering drawings. The range of these processes varies with the design practices of a company, the manufacturing facilities available to them, and the constant improvement in manufacturing methods. A few of the basic manufacturing processes will be discussed in this chapter, together with the special information appearing on the drawing relative to these processes.

8.2. Sheet-metal Fabrication.—Approximately half thes tructural weight of a modern all-metal airplane is composed of flat sheets of metal cut, bent, and formed into a variety of shapes. The metal sheets most frequently used in aircraft construction are (*a*) aluminum alloy covered with a thin layer of pure aluminum to prevent corrosion, (*b*) magnesium alloy, and (*c*) various types of steel, such as corrosion-resistant steel, low-carbon steel, and chrome molybdenum steel. The type of metal selected for a particular part is governed by its properties: lightness, strength, resistance to corrosion, availability, behavior when subjected to high temperatures, weldability, and malleability and ductility, *i.e.*, how well it will withstand bending, stretching, and shrinking.

The simplest operation performed on sheet metal is shearing or cutting. Straight cuts that do not pass through any other part of the sheet are made by a shear having a fixed and a movable blade; metal sheets placed between the blades are cut or sheared by an action similar to that of a pair of scissors cutting a piece of paper (see Fig. 8.1). Curved cuts may be made on a circular shear that cuts the metal between two sharp steel disks overlapping each other, with an action similar to that of a butcher's meat slicer (see Fig. 8.2). The circular shear is slow and cannot cut a sharply curved contour. A faster and more useful production method for cutting flat sheet metal into con-

toured shapes is routing. The cutting instrument is a slender cylindrical tool, similar to a drill, which rotates at high speed. A number of sheets are cut out at once by being stacked beneath

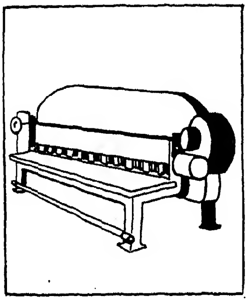


Fig. 8.1.—Straight shear.

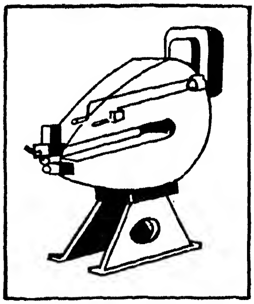


Fig. 8.2.—Circular shear.

a template or cutter guide; the router bit is guided around the contour of the template, thus nibbling away the metal outside the desired shape (see Fig. 8.3). Sharp notches cannot be cut

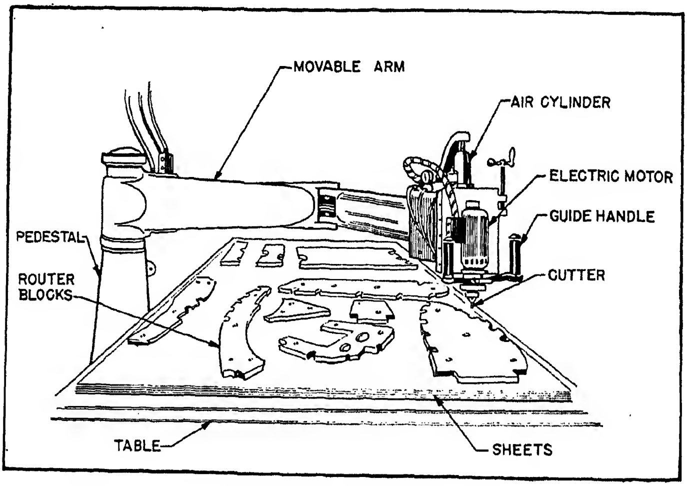


Fig. 8.3a.—Router.

out on a router, the minimum radius possible being that of the cutter, usually 5⁄32 in. Sharp notches in a part are poor design, since cracks tend to begin at a sharp notch that is not filleted. Figure 8.4 illustrates parts designed for shearing and for routing.

Straight bends in sheet-metal parts, such as the flanges in the parts shown in Fig. 8.4, are made on a brake. A brake consists

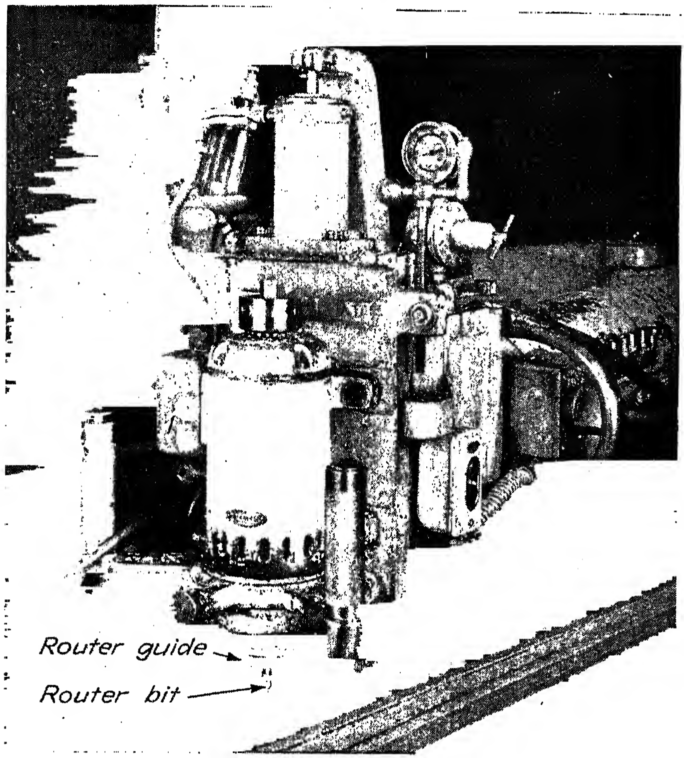


FIG. 8.3b.—Router head.

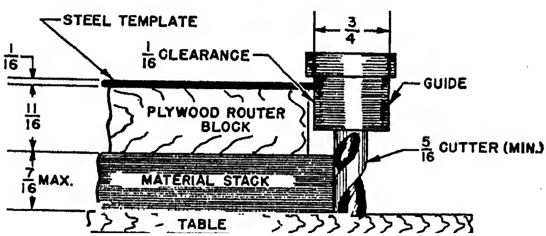
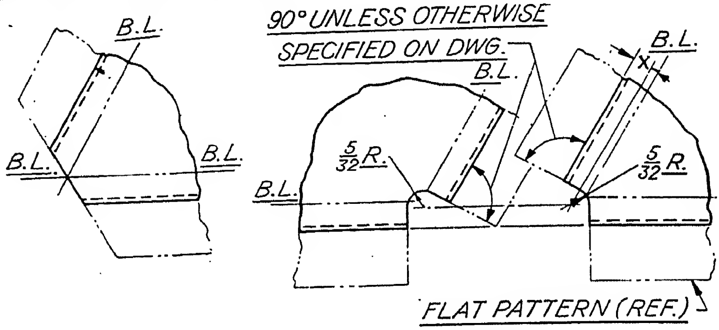


FIG. 8.3c.—Router cutter, template, and material.

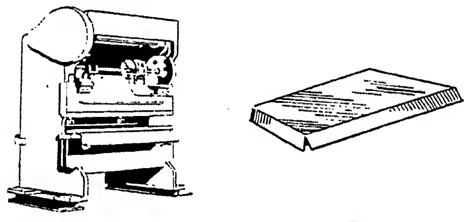
of a fixed die with a trough running the length of it and a movable wedge-shaped block which will enter the trough in the fixed die. The metal to be bent is placed between the block and the die,

and the dies are brought together (see Fig. 8.5). By using different shaped dies and by adjusting the separation of the dies when closed, the radius of the bend and the angle between

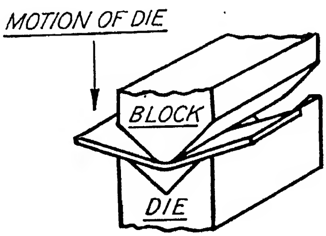


a. Shear *b.* Router

FIG. 8.4.—Shear and router parts.



a



b

FIG. 8.5.—Power brake.

the flanges may be varied. The length of a flange is always dimensioned to the intersection of the flanged surfaces, termed the "heel line," and not to the tangent point of the radius or to the radius center, since the former dimension can be checked or inspected easily on the finished part while the latter cannot

(see Fig. 8.6). The length of sheet that can be bent in a brake is limited by the size of the brake. An infinitely long sheet can be bent by a set of rolls, several bends being accomplished simultaneously. These rolls have the same shape as the desired bent sheet, and when flat metal is fed into them, they bend it by a continuous process (see Fig. 8.7). The rolls are expensive but, if used for quantity production, this cost is repaid many times over by the high rate of production.

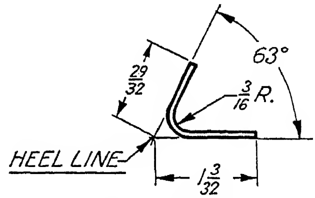


Fig. 8.6.—Dimensioning flanges.

An efficient production method of shearing (or blanking) and also forming sheet-metal parts is accomplished by the punch

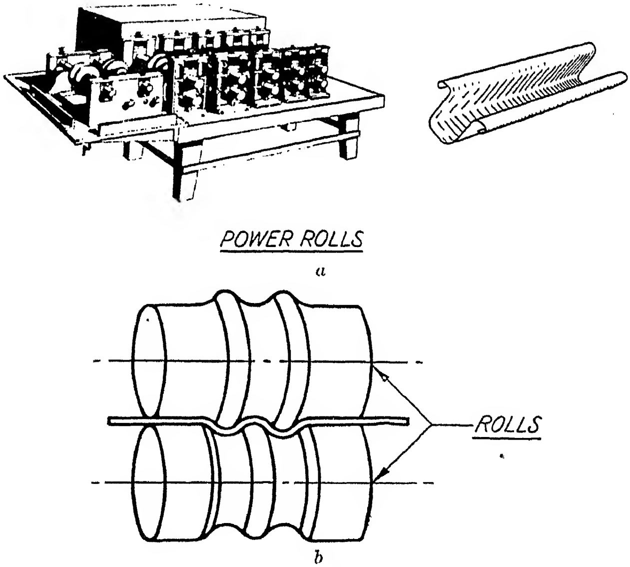


Fig. 8.7.—Power rolls.

press (see Fig. 8.8). The tools required to produce parts on a punch press are called "dies." These dies are quite expensive, since they are made of tool steel and require very close precision work by expert tool and die makers. The dies are capable of piercing, blanking, and forming accurate parts in great quantity with infrequent resharpening of the dies.

The most common die, called a "piercing and blanking die," consists essentially of a male punch, a female die, a stripper plate (to strip the scrap from the punch), and various stops, guides, and attachments for mounting the die to the punch press (see Fig. 8.9). The female die is fastened to the bed of the punch press, while the punch and the backing plate are bolted to the movable ram of the press. The metal stock is fed into the die between the stripper plate and the die block. The ram of the press forces the punch through the metal stock and into the die below, thereby piercing and blanking out through the bottom of the die the exact shape of the desired part. The ram raises the punch back out of the die, while the stripper plate strips the metal stock from the punch. The metal stock is fed another step through the die, and the operation is repeated.

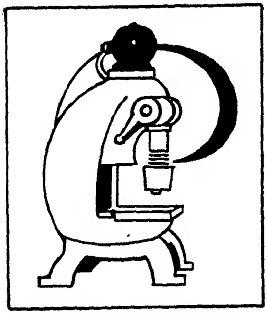


Fig. 8.8.—Punch press.

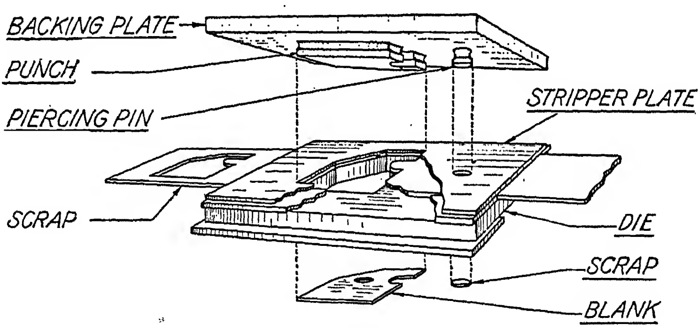


Fig. 8.9.—Punch press die.

A method of shearing and forming parts similar to the punch-press method but involving much less expensive dies is called "the hydro-press method." This makes use of a form block placed beneath a hydraulic ram capped by a very thick sheet of rubber (see Fig. 8.10). The enormous pressure of the rubber forces the sheet metal to deform to the contour of the form block, as illustrated in Fig. 8.11. These form blocks are usually made of a hard pressed-wood product such as masonite. Where it is desired to shear off the metal, a sharp-edged steel plate is inserted

in the form block. The pressure of the rubber pad, backed by the hydraulic ram, against the steel plate shears off the sheet

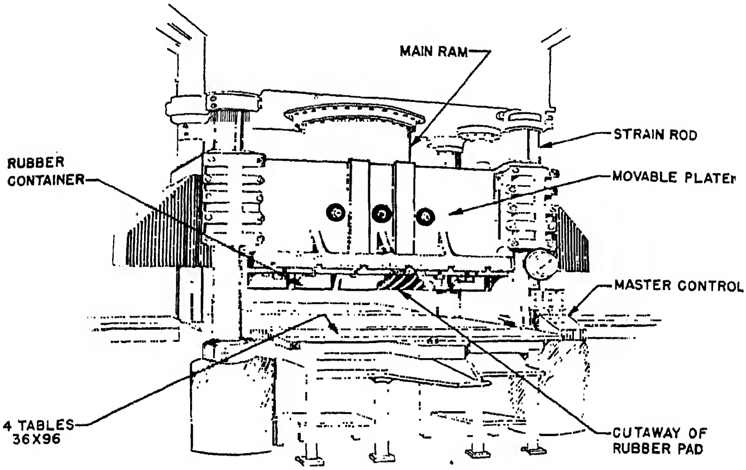


Fig. 8.10.—Hydro press.

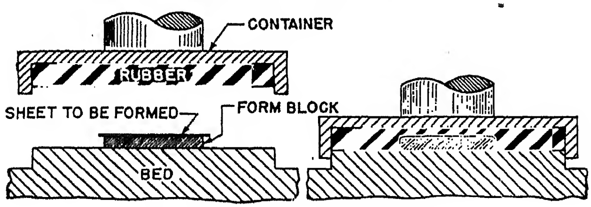


Fig. 8.11.—Hydro press forming.

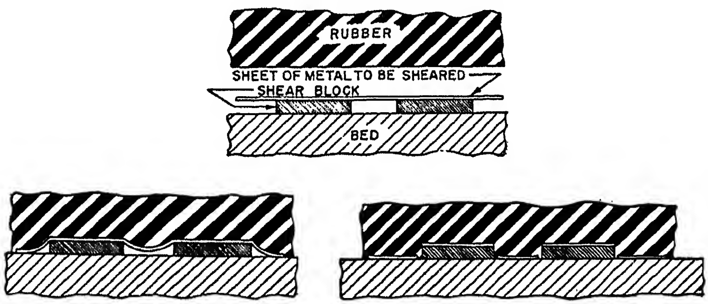


Fig. 8.12.—Hydro press shearing.

metal as a pair of scissors cuts paper (see Fig. 8.12). The type of metal sheet used in this process must be reasonably soft so

that it can be stretched, shrunk, and trimmed by the hydro press, without wearing out the rubber pad. Typical hydro press rudder and flap ribs are shown in Fig. 8.13.

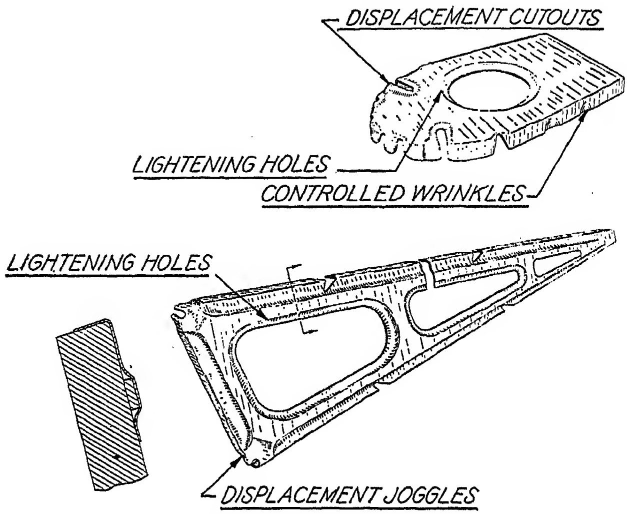


Fig. 8.13.—Hydro press parts.

The use of the hydro press is limited by the unit pressure required to stretch or to "work" the metal. If the original sheet must be deeply formed, or if the metal to be formed is quite hard, such as stainless steel, the drop-hammer method may be employed. However, this method is very slow and quite expensive. Drop-hammer dies are made by pouring molten zinc over a plaster cast of the shape of the required part, producing one-half of the die. When the zinc die has solidified, molten lead is poured into the recess left in the zinc die by removing the plaster cast, thus forming the mating lead die. The zinc die is bolted to the fixed bed of the drop hammer, and the lead die is bolted to the moving hammer which travels on a vertical track. The hammer is hoisted mechanically, then the sheet to

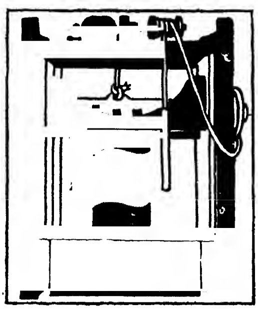


Fig. 8.14.—Drop hammer.

be formed is placed on the zinc die, and the hammer is allowed to fall on the sheet, forcing and stretching it into the desired shape (see Fig. 8.14).

The stretching machine forms sheet metal by seizing the ends of a sheet in two sets of jaws and by pulling, bending, and stretching it over a form (see Fig. 8.15). The form block or die is mounted on a ram which rises by hydraulic pressure, stretching

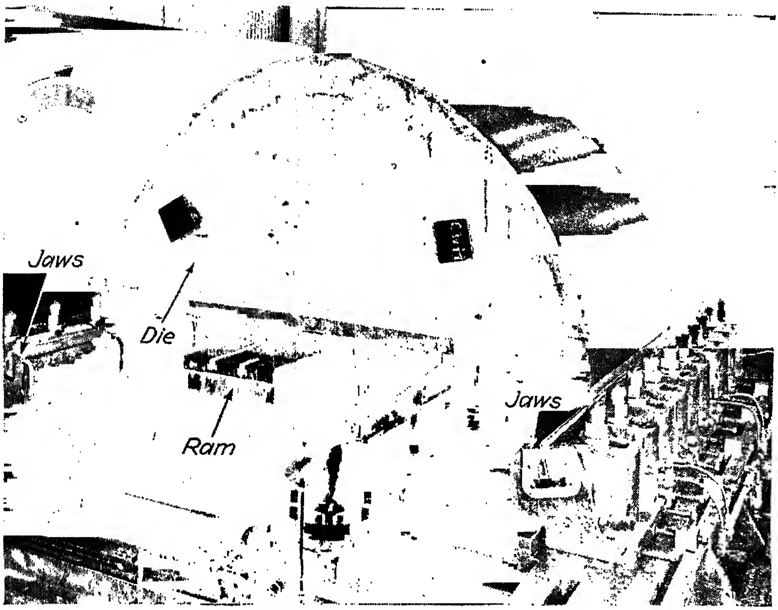
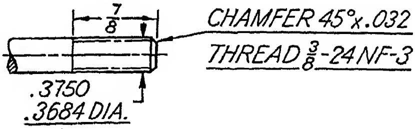


Fig. 8.15.—Stretching machine.

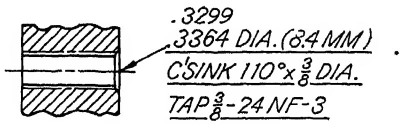
the sheet metal to the form of the block. When the form block is lowered by the ram, the stretched sheet metal, formed to the desired shape, is removed from the jaws, and the excess metal around the edges of the sheet is trimmed off.

The oldest and most expensive method of forming sheet metal is hand forming, in which a workman laboriously beats the metal with a hammer or a rawhide mallet until it assumes the required shape. Some hand forming is still employed in the aircraft industry where high-rate production methods cannot be adapted. This method is used only where a very few parts are required and where the expense of mass-production methods is not warranted.

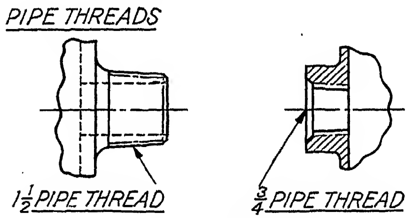
8.3. Threads, Splines, and Gears.—The accurate drawing representation of threads, splines, and gears is a tedious, time-consuming task. Since these processes have been standardized—tools and manufacturing processes being common in machine



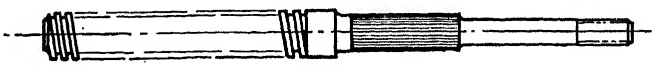
a. Male thread



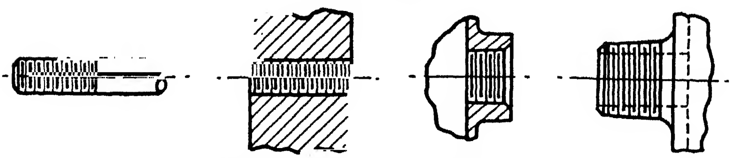
b. Female thread



c. Pipe threads



d. Acme thread



e. Diagrammatic representation of threads

FIG. 8.16.—Threads.

shops all over the country—the drawing is a diagram, the exact data being covered by a note and sometimes by an enlarged view of one or two teeth for special types of threads, splines, or gears. Typical representations of threads are shown in Fig. 8.16; Figs. 8.16*a* and 8.16*b* are male and female machine threads; Fig. 8.16*c* illustrates male and female pipe threads tapered to

produce a fluid tight joint; Fig. 8.16*d* is an acme or flat-topped thread used where the threads must rotate under load. The top representations in Figs. 8.16*a*, 8.16*b*, and 8.16*c* are the most common, using visible or invisible outlines to represent the peak of the thread and phantom lines to represent the valley of the thread. A less desirable method is shown in Fig. 8.16*e*. Light, long lines alternate with shorter, heavy lines, representing the peak and the valley or the major and the minor diameters of the thread. The lines should be evenly spaced and should approximately equal the pitch of the thread, *i.e.*, the distance from one peak to the next. The short lines should all be the same length; faint guide lines will assist in keeping the length uniform. All threads are assumed to be right-hand threads unless specifically indicated by a prominent note in large letters, "LEFT HAND THREAD." In Fig. 8.16*d* only the first few threads are shown to indicate where they start; the remainder of the threaded area is represented by solid and phantom lines.

Like threads, the teeth of splines, serrations, and gears are shown diagrammatically, using outlines to indicate the peak and phantom lines to indicate the valley (see Fig. 8.17). Splines and serrations are used in connecting two parts, such as a shaft and a wheel or two shafts, so that they will rotate as one part. Gears are used to transmit and to change the angular speed and the direction of rotating motion.

8.4. Machining Operations.—The aircraft industry makes use of practically every machine that will produce aircraft parts more accurately, more quickly, and more cheaply. Drawings show the finished part without specifying how it shall be made. Expert employees, called "planners," determine what methods and machines shall be used in the fabrication process. Nevertheless, the designer and draftsman of aircraft parts must be thoroughly familiar with all phases and the latest up-to-date methods of the manufacture of aircraft parts.

Machining, in almost all cases, is accomplished by the object rotating against a fixed tool or by the tool rotating against the object. A lathe is an example of the former; the material to be machined is clamped in rotating jaws and a tool is brought against it, cutting the material down to the required diameter. Both male and female threads are turned on a lathe, as are shafts and bored holes. Drilling is an example of a rotating tool operating

on a fixed object. "Counterdrilling" is the term applied to drilling an oversize hole part way into a previously drilled hole. Spot facing is a method of smoothing and squaring the area or surface immediately surrounding a hole. A spotfacer is similar to a drill except that it is flat on the end and has cutting teeth or flutes on the end instead of on the sides. When spot facing

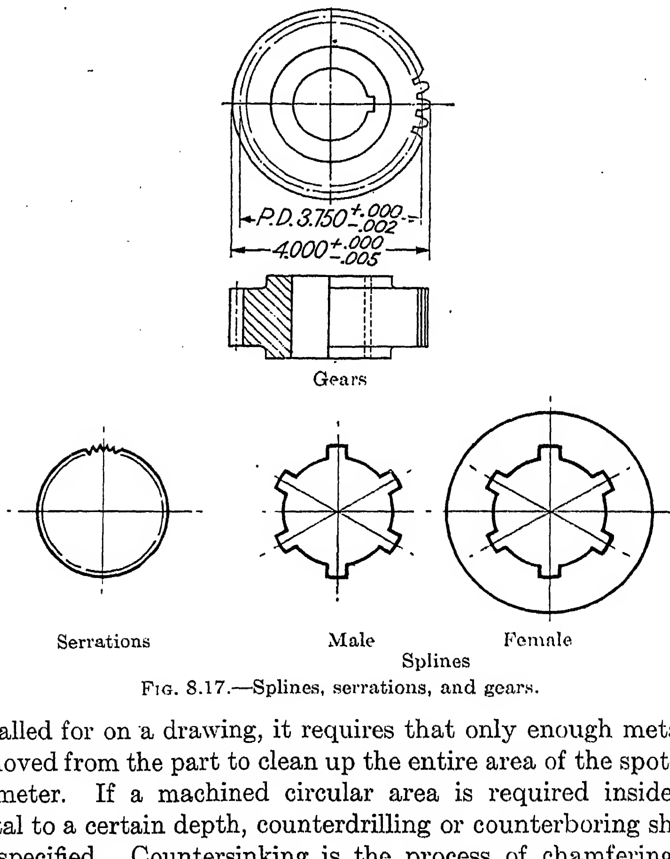


FIG. 8.17.—Splines, serrations, and gears.

is called for on a drawing, it requires that only enough metal be removed from the part to clean up the entire area of the spot-face diameter. If a machined circular area is required inside the metal to a certain depth, counterdrilling or counterboring should be specified. Countersinking is the process of chamfering the exterior sharp edge of a hole, making it funnel shaped in the countersunk area. The angle between the sides of the countersinking tool and also the diameter of the large end of the countersunk hole are specified by a note on the drawing. Boring is a process for cutting holes more accurately and larger than can be drilled. The cutting tool is fastened to a rotating shaft

where it protrudes sideways a distance equal to the radius of the hole to be bored, and is gradually advanced into the hole, cutting out the required diameter. Reaming is the process of producing a very accurate, smoothly finished hole. The reamer is a tool similar to a drill except that it cuts on its sides rather than on the end by means of lengthwise flutes. The diameter of a reamed hole may be held to ±.0005 in. Small holes are

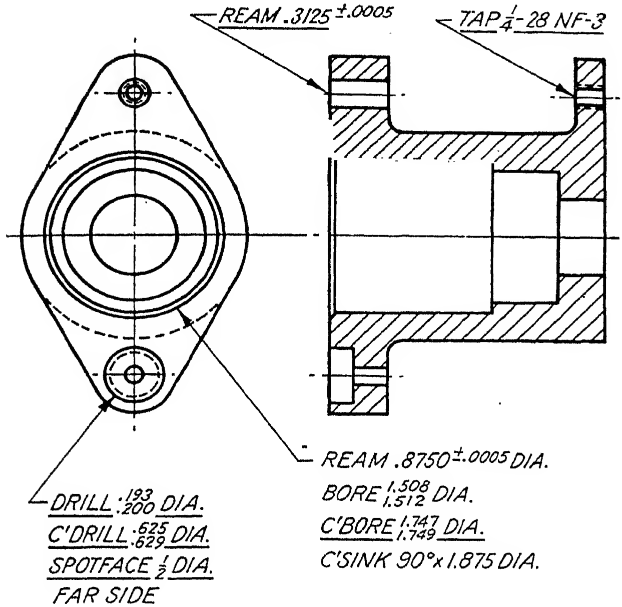


FIG. 8.18. Machining notes.

threaded with a tap that looks like a screw with the threads decreasing in diameter and with slots cut lengthwise along the tap to form a cutting edge and a recess for chips. The small end of the tap enters the hole and as the tap is rotated, each succeeding thread cuts out the threads in the hole a little deeper until a perfect thread is formed. The tap is then rotated in reverse, screwing itself out of the hole. Figure 8.18 illustrates the notes used to call for some of the above operations.

Metal may be sawed by circular, band, or blade saws. Sawed surfaces are rough and are usually finished smooth by further

machining. Milling is often used to clean up rough surfaces as well as to make entire cuts. Milling is probably the most versatile type of machining and is performed by a rotating cutter under which an object can be moved in three different directions. Cutters come in a variety of shapes and sizes to perform different types of milling jobs. A milling cutter is similar to a thick, circular saw blade with teeth around the circumference and also on each side, extending radially from the shaft which rotates it; this cutter can cut on three sides at once. A fly cutter has radial teeth on its circular surface and can cut on that surface only. A ball-end cutter is self-descriptive. Whenever a machined surface appears on edge, it is indicated by the symbol, *f*. The drawing also contains a general note describing the finish type, usually a smooth machine finish. The specifications of a company define the requirements of a finish, and in some cases the *f* mark is terminated by a circle in which is included a number that stands for a particular grade of finish, for example, ③*f*. The short crossbar of the *f* mark and the main line of the *f* intersect at the finished surface line.

Grinding is the process of removing metal by the action of a grinding wheel composed of fine particles of a very hard substance such as Carborundum. Grinding wheels do tasks ranging all the way from removing large knobs from castings and forgings to mirror finishing of shafts and holes to a tolerance of a fraction of $\frac{1}{1000}$ in. Disk grinding is a quick, cheap method of producing a flat surface of reasonable smoothness. The surface to be smoothed, usually a rough cast surface, is held against the flat side of a large revolving grindstone until all bumps and depressions left by the casting sand are removed. Disk grinding is specified on a drawing by pointing an arrow to the surface to be so finished where that surface appears on edge with the note "Disk Grind." Sandblasting is a process for removing scale or other soft adherences from an object by directing a mixture of air and small abrasive particles at high velocity against the surface to be cleaned. This is a very common method for cleaning up objects but is usually not specified on a drawing unless required as a specific surface finish.

8.5. Attaching Parts.—The most common method of joining separately fabricated parts into an assembly is by riveting. The

prefabricated heads of rivets are designated as round head for the majority of riveting inside the airplane, as flush head for external surfaces and for internal surfaces requiring a flat surface, and as brazier head where flush heads are not required but where round heads protrude too far. The rivet shank is slipped into the holes in the parts to be joined, and the shank is hammered or squeezed until the part of the shank that protrudes beyond the hole is flattened out, forming a head on the opposite end from the prefabricated head (see Fig. 8.19). Rivets are usually of the same material as the parts they join and are never of harder

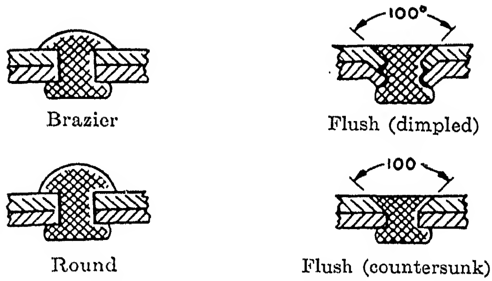


FIG. 8.19.—Types of rivets.

material. They are classified as to size by the diameter of the shank. In showing rivets in cross section, the shop-formed head for all types of rivets is depicted as a semicircle identical to the prefabricated head of a round-head rivet. For pictorial purposes the diameter of round- and flush-head rivets is twice the diameter of the shank, and the brazier head is $2\frac{1}{2}$ times the diameter of the shank. In showing rivets in a plan view, the dotted circle indicating the shank may be omitted, while in long runs or rows of rivets, the outer circles should be shown for a few rivets at each end of the run, and the remainder of the rivets should be indicated by the intersection of the center lines locating their position. If the run is dimensioned with a constant spacing, such as "$1\frac{5}{16}$, $1\frac{5}{16}$, etc.," the crossing center lines may also be omitted in the center part of the run. The drawing must always call for the hole size required for the rivets; usually, this is slightly larger than the diameter of the rivet shank, *e.g.*, a .128 diameter hole for a $\frac{1}{8}$ diameter rivet.

To drive the rivets discussed above, it is necessary to have access to both ends. Special rivets have been developed that

can be driven from one end only. One type, called an "explosive rivet," contains a small charge of explosive in the hollowed-out end of the shank (see Fig. 8.20). After inserting the rivet in the hole, a hot iron is applied to the head of the rivet, the heat is conducted through the shank to the charge, exploding it and forming the rivet head. Another type of blind rivet is an expanding rivet which is hollow along its entire length. Inside this hole is a shaft with a small swelling at its shank end that protrudes outside the head (see Fig. 8.21). After inserting the

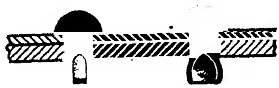


Fig. 8.20.—Explosive types of blind rivets.

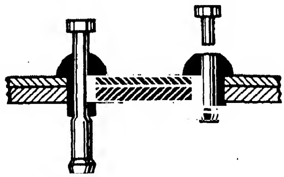


Fig. 8.21.—Mandrel type of blind rivets.

rivet the shaft is drawn out, forcing the swelled end into the hole in the shank, which in turn is forced out, producing a head. Blind rivets are more expensive, harder to drive, and usually weaker than ordinary rivets; assemblies should be so designed as to avoid their use if possible.

Machine screws most commonly used in aircraft construction are round, flush, and brazier head. In a plan view, the slots are usually shown sloping 45 deg., while in a section the slots are shown normal to the plane of the paper. Omission of detail in showing rivets also applies to showing machine screws. For high-strength joints, hexagonal-headed bolts are usually employed. Their strength and dimensional tolerances are rigidly maintained by an Army-Navy (AN) specification. Clevis bolts are similar to brazier-head screws except that the threaded portion of the bolt is very short, and the shank diameter is held to very close tolerances. The bolt is used to pin two rotating parts together, such as a pulley in a pulley bracket or a cable fitting in a bell crank. If it is required to pin a crank to a shaft without motion between the crank and shaft, a taper pin is sometimes used. The shaft of the pin is tapered in diameter, there is no head on the pin, and the small end is threaded. The two members to be joined are taper-reamed together, the taper pin is inserted, and the nut is tightened until the pin fills the

hole in both parts tightly. Sheet-metal screws are made of hard steel and they taper slightly toward the threaded end. They are screwed into a slightly undersized hole and tap their own threads in the hole. Due to the taper in the screw threads, they fit quite tightly and resist being shaken loose.

All nuts, bolts, and screws used on an aircraft must be secured against vibration so that they will not loosen and fall off in flight. Plain hexagonal nuts with lock washers that dig into the nut when it is unscrewed are sometimes used but are not desirable since, when unscrewed, they mar the nut and the plain washer placed between the lock washer and the metal to be secured. Moreover, although the nut is prevented from turning by the lock washer, the bolt or screw may vibrate loose. The most firm retention of nuts is obtained by a bolt with a small hole drilled through it near the threaded end and a castellated nut having three slots cut across its crown. The nut is tightened until one of the three slots is aligned with the hole in the bolt; a cotter pin is inserted through the hole in the bolt and the slot in the nut, and the legs of the cotter are bent, one down the side of the nut and the other over the top of the bolt. The nut cannot possibly back off without shearing off the cotter pin. The adjusting of castellated nuts so that the cotter pin may be inserted is a slow process, and the nuts cannot always be tightened up, since they may have to be backed off one-sixth of a turn in order to align the slot and hole. Wherever parts rotate on the bolt, castellated nuts must be used, as in the bolt securing a pulley or a rotating bell crank.

The most practical nut for aircraft work is the self-locking nut in which a fiber or soft-metal washer is incorporated in the top threaded part of the nut. The hole in the washer is slightly smaller than the outside diameter of the screw; as the screw enters the threaded part of the nut, it turns freely, but when it comes to the fiber washer, it must force its threads into the washer, making the turning difficult. These self-locking nuts are quickly installed, they may be tightened to the proper degree, and they will resist loosening by vibration quite satisfactorily. They may be removed and reinstalled several times before their self-locking characteristics are impaired. It is sometimes impossible or very difficult to hold the nut while installing a bolt or screw. Nut plates, which are self-locking nuts with two ears, are riveted

on while the area is still accessible so that the screw or bolt can be inserted later and tightened without holding the nut. Bolts with drilled holes in the threaded area must not be used with self-locking nuts or nut plates, since they cut the fiber locking washer, spoiling its retaining grip on the threads. To ensure locking, at least one full thread of the screw or bolt must extend beyond the end of the nut or nut plate. Figure 8.22 shows

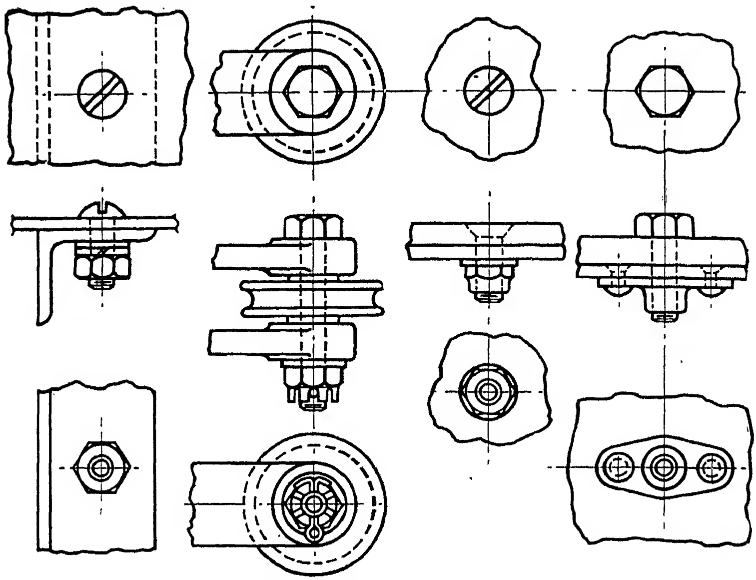


Fig. 8.22.—Bolts, nuts, and screws.

typical drawing representations of nuts, bolts, and screws. In addition to the screws, bolts, and nuts described above, many special fasteners are available: high-stress bolts, light sheet-metal nuts and nut plates, quick-attach fasteners which can be installed or removed with a quarter turn of a screw head, etc. Their description and special usages, however, do not fall within the scope of this text.

8.6. Cables and Fittings.—Because of their flexibility, lightness, and strength, cables composed of many strands of steel wire twisted together are used in control systems of airplanes or where a pull is to be transmitted around corners or over long distances. A cable of ⅛ in. diameter (about the same thickness as a kitchen match) requires more than 2,000 lb. to break it.

In order to make full use of the strength of a cable, a means must be devised of attaching the cable to the device which it operates. Formerly, cables were wrapped around a small spool or thimble and the cable was spliced or was lashed and wrapped back upon itself; the spool or thimble was then bolted to a bell crank or fitting operated by the cable. These splices are bulky and tend to be weaker than the cable. Today, the accepted practice for attaching fittings to cable ends is by swaging. The cable is inserted into a hole only slightly larger than the cable; the metal of the fitting surrounding the hole is squeezed down, or swaged, onto the cable so that the fitting grips the cable securely. Swaged cable fittings will usually develop more strength than the cable itself, that is, the cable will break before it is pulled out of the fitting.

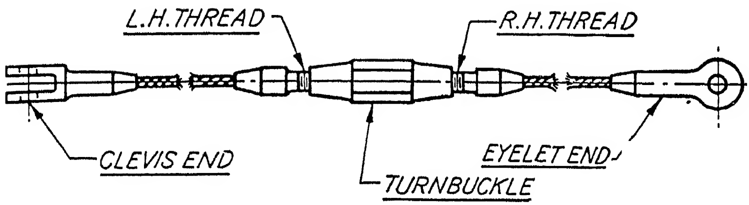


FIG. 8.23.—Cable fittings.

Aircraft cables usually must be kept taut so that motion of one end of the cable will be transmitted to the other end without delay or lag; this is especially important in large airplanes where cable runs may be as long as 100 ft. Additional tautness must be provided to keep the cables responsive at cold temperatures encountered in high-altitude flying. Cold temperatures cause all metals to contract, but since aluminum alloy contracts more than steel for a given decrease in temperature, the framework of an aluminum alloy airplane shortens more than the cable, causing the cable to tend to sag. Aluminum alloy cables are being developed to eliminate this condition but are not yet in general use. The tautness of cables is adjusted by turnbuckles which consist of a barrel or tube, threaded left-hand through half its length and threaded right-hand through the other half, and a right-hand and a left-hand threaded cable end fitting. Each threaded end of the fitting is started in the proper end of the turnbuckle barrel. With the fittings held stationary,

rotation of the barrel causes them to screw into or out of the barrel simultaneously, tightening or loosening the cable. Various types of cable-ends have been adopted as Army-Navy standards. Figure 8.23 illustrates the typical drawing representation of standard cable fittings.

8.7. Welding.—Welding is the process of joining two objects composed of similar or identical material by heating them

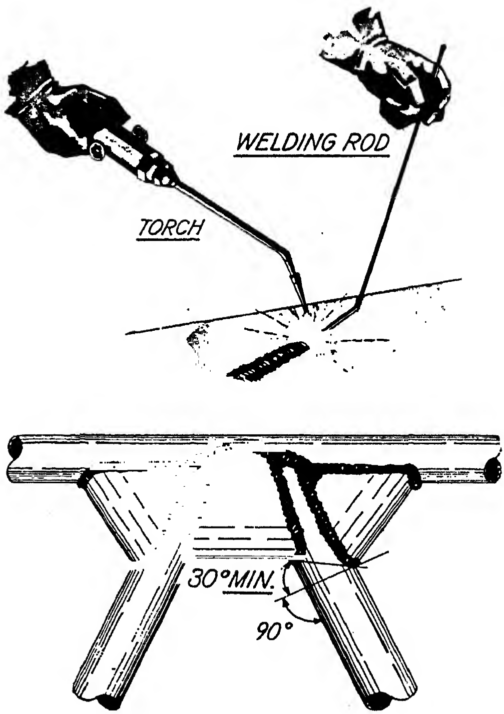


Fig. 8.24.—Torch welding.

locally, in the area to be joined, until molten; the molten metal flows together and when cool joins the two objects. In torch welding, the objects are heated by an oxygen-acetylene flame, with additional metal being built up at the weld from a welding rod of similar metal. Flux is applied to the area to be welded to cause the metal to flow easily and smoothly as it melts (see Fig. 8.24). In arc welding a strong electric current flows through the welding rod and the material to be welded when the welding

rod is brought in contact with the material. The high electrical resistance of the contact point between the welding rod and the material produces sufficient heat to fuse the rod and the material, thus producing the weld (see Fig. 8.25). Spot-welding is a method of joining two or more sheets of metal, one laid flat

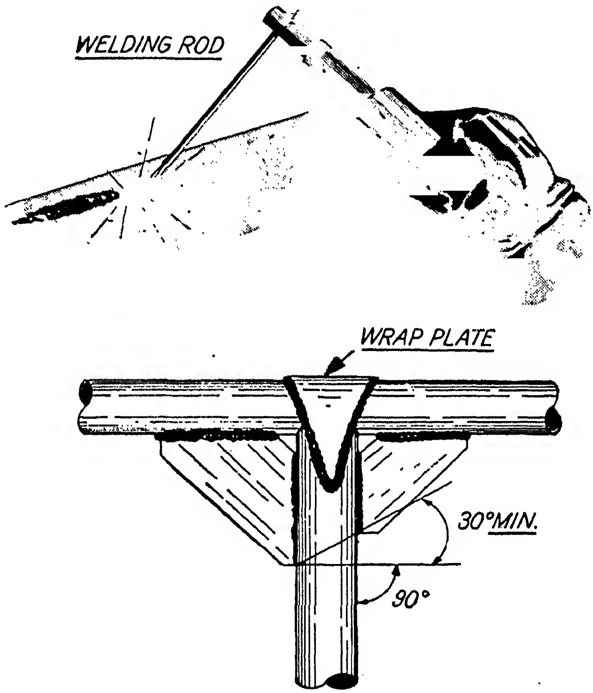


FIG. 8.25.—Arc welding.

against the other, by fusing them at local spots of about ⅛ in. diameter (see Fig. 8.26). The sheets are placed between two electrodes, one above the other, and the electrodes are brought together until they touch the sheets, one on each side. The electric current flowing through the sheets welds them together at a local spot the diameter of which may be closely controlled. Roll-seam welding produces a continuous spot weld by using electrodes which are wheels (see Fig. 8.27). The sheets are rolled between the wheels, leaving a continuous weld where the wheels touch the sheet.

Flash welding is one of the most interesting types of welding, as it is cheap, fast, light, strong, and neat in appearance (see Fig. 8.28). Two parts of identical cross-sectional shape are clamped in dies, one fixed and one movable; each die acts as an electrode so that when the movable die brings one part into contact with the other, the electric current fuses the metal at the point of contact, building up a strong, uniform weld. Light, strong push rods are fabricated by flash welding end fittings

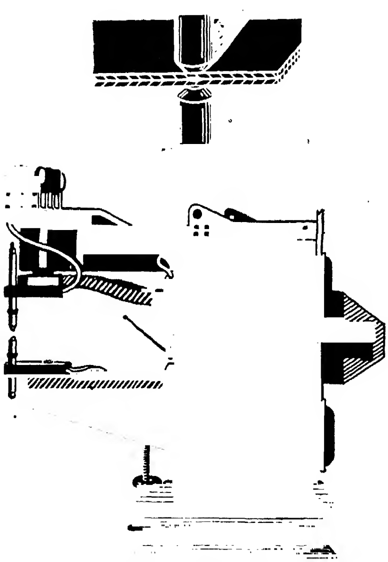


FIG. 8.26.—Spot welding.

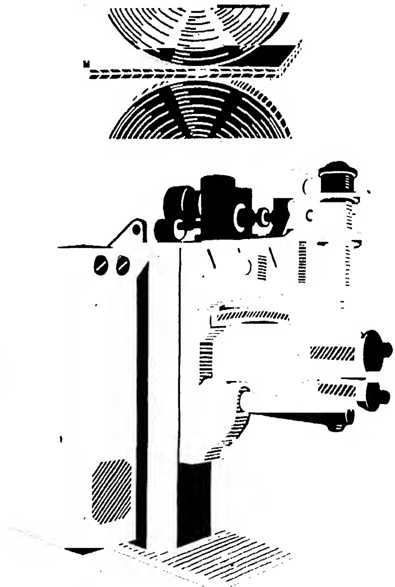


FIG. 8.27.—Roll-seam welding.

to a steel tube; the welded area is usually stronger than the tube itself. All the types of welds discussed here have limitations both as to the kinds of metals that can be welded and the kinds of loads to which they can be satisfactorily subjected. Figure 8.29 shows the drawing representations of various types of welds.

Iron and steel are cut by an oxyacetylene flame that travels in the direction of the desired cut while melting and burning away a slot in the metal. The torch-cut edge is not so smooth as a machine-cut edge, but the process is cheaper than machine cutting. Special pantograph torches will follow the outline of an irregularly shaped template and cut steel to an identically irregular outline.

8.8. Forgings.—Forgings, castings, and moldings are all produced by forcing or pouring metal or other material into an irregular-shaped opening to produce an irregular-shaped object

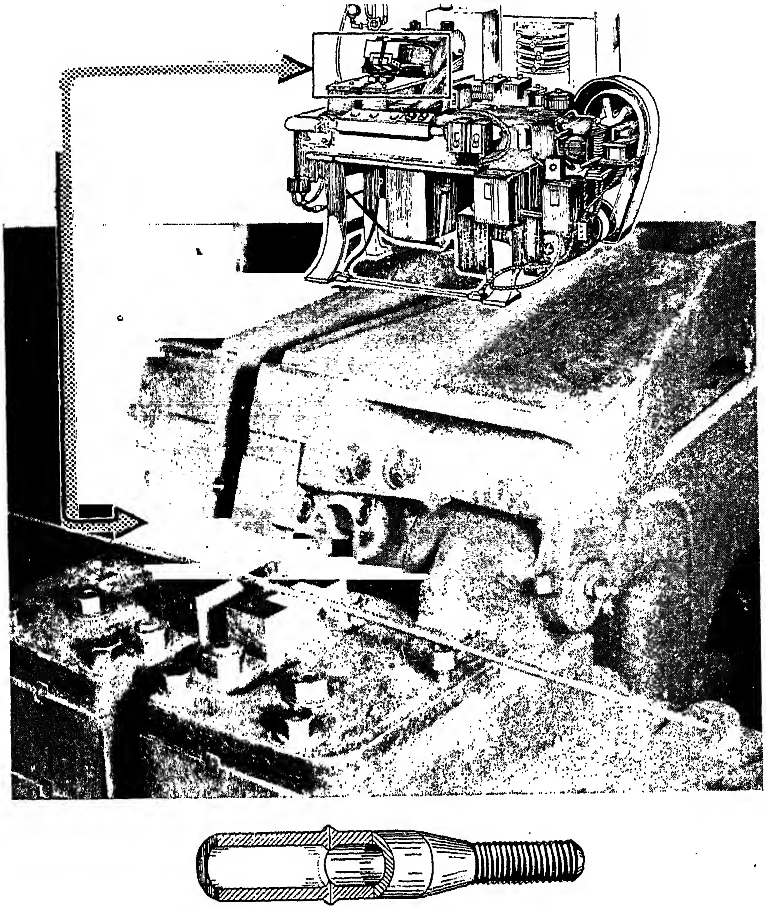


Fig. 8.28.—Flash welding.

requiring little additional fabrication to become a finished part. Very complicated and expensive machine work would be required to produce the same shape by machining or "hogging" the object from a solid block of material, with an attendant waste of material.

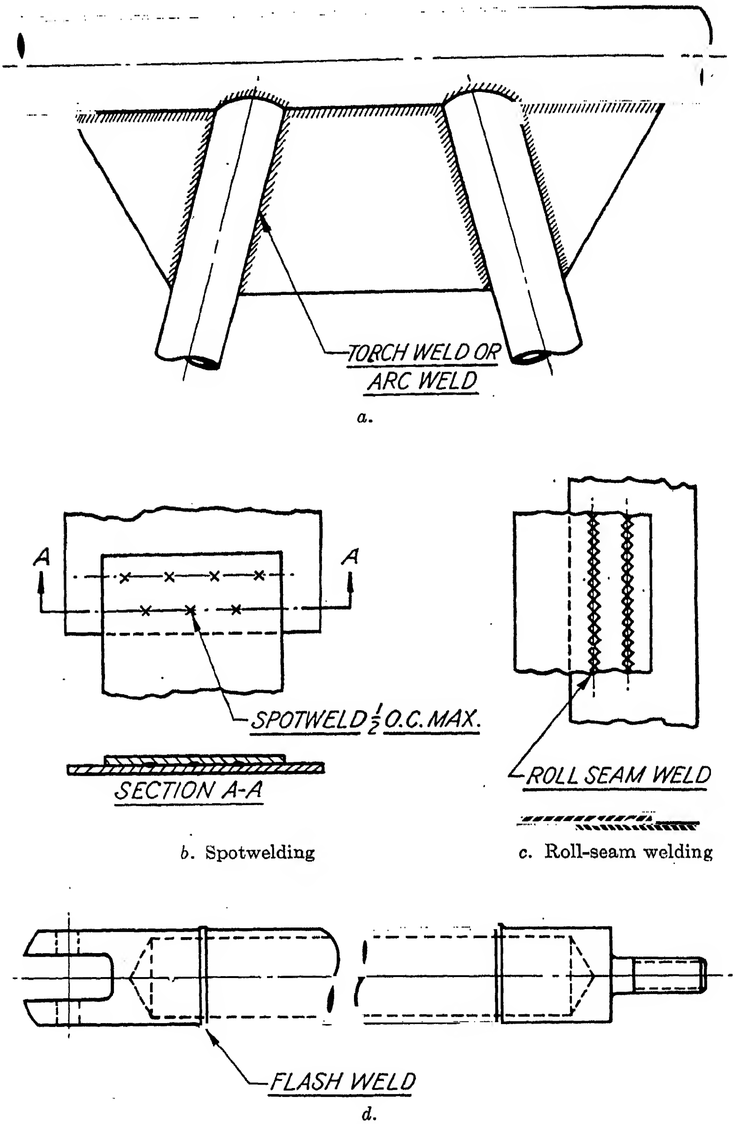


FIG. 8.29.—Drawing various types of welds.

Forgings are produced by heated metal, usually aluminum alloy or steel, being hammered between two die blocks. Each die block is hollowed out to the shape of part of the forged object; one block is fixed, while the other is fastened to the moving head of a hydraulic ram in such a position that when the ram brings the moving die against the fixed die, the two hollows in the dies form the exact shape of the desired object. The rough metal or billet is hammered between the two dies, gradually assuming the proper shape until the two dies are brought

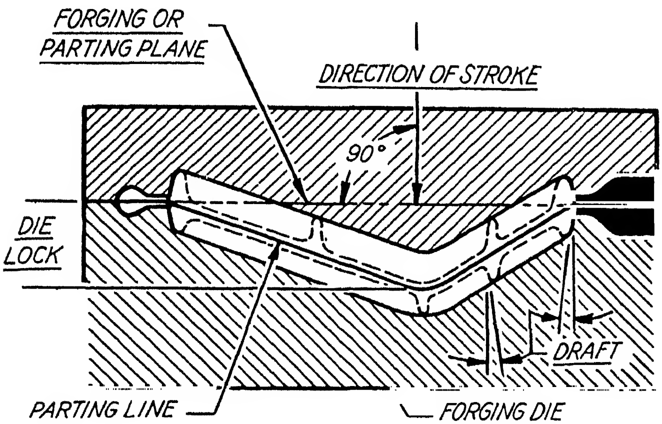


Fig. 8.30.—Forging die terms.

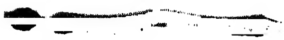
together; it then completely fills the hollows in the dies and is in its final shape. Forgings are expensive due to high die and manufacturing costs. They have the advantages of great strength, uniformity of size and shape, and smooth surfaces which require little, if any, machining; these properties offset their high cost, especially where large quantities are used.

The plane on the forging which marks the boundary between the fixed and the moving dies is called the "parting plane" (see Fig. 8.30). Corners are always rounded or generously filleted to permit the metal to flow around and into them during the forging process; sharp recesses and corners must be avoided to prevent breaking the dies. Webs, or masses of metal, should become thinner as they extend away from the parting plane so that as the dies are separated, the forging may easily be separated from either die. The slope of the surfaces is called "the draft"

and is usually a minimum of 7 deg. from the direction of the forging die movement (usually perpendicular to the parting plane). Forgings must always be so designed that, as the dies are separated, the gap between the forging and the die grows. Figure 8.31 represents the progressive steps used in the forging

1. Original bar

2. Bar lengthened and reduced in cross section by the fullering die

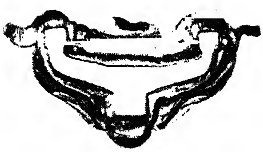


3. Metal distributed roughly where needed by the edging or rolling die

4. Piece bent to produce desired grain flow by the bending die

5. Piece formed to nearly its final shape by the blocking die

6. Piece reduced to desired shape and size by the finish die



7. Excess metal or flash sheared off by the trimming die

8. Completed forging

FIG. 8.31.—Progressive steps in the forging process.

process; Fig. 8.32 illustrates the plan view of a forging, visible outlines representing the intersection of the draft surfaces with the top and bottom planes of the forging. According to strict orthographic projection no lines would appear at these places, since they are smooth surfaces not perpendicular to the plane of the paper. However, without these lines to show the contour of the forged webs, the drawing would not be clear and might consist solely of the outline of the forging; this deviation from usual orthographic projection is commonly followed in drawings of forged parts. Hot pressings are similar to forgings except

that the metal is somewhat hotter while forming and is pressed into shape by a single closing of the dies rather than by repeated hammering.

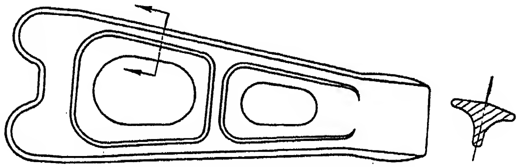


FIG. 8.32.—Plan view of a forging.

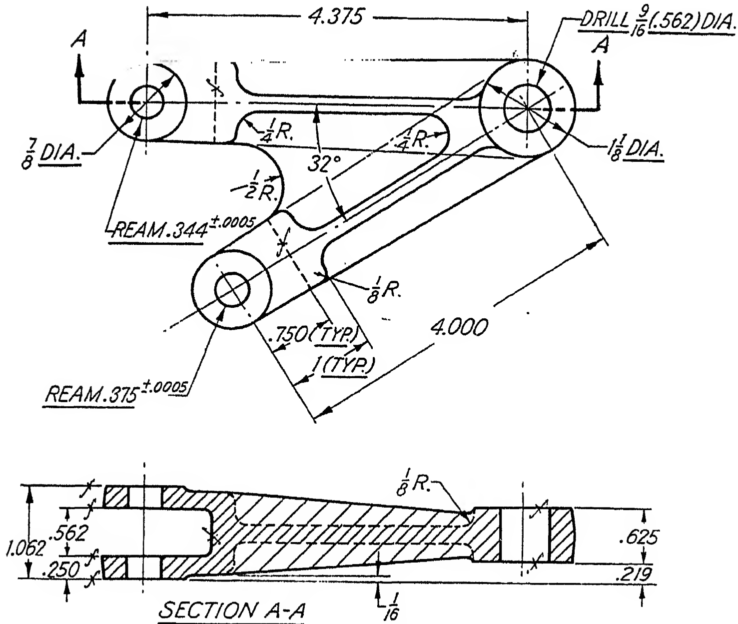


FIG. 8.33.—Link—gear door operating.

Exercises

8.8.1. Drawing 58, Forging—Gear Door Operating Link.—Figure 8.33 shows a plan view and a section typical through both ribs of a link machined from a forging. Draw the forging from which the link of Fig. 8.33 was machined. The slots and the holes are forged solid, and additional forged material ⅛ in. thick is added to all finished external surfaces of the finished machined part. The finished surfaces of the machined part are indicated by the ƒ symbol, all webs are 3/16 in. thick, and all fillets are ⅛ in. in radius. The draft angle is 7 deg.; the parting plane may be determined by

inspection of the finished machine part. The thickness of the webs, the size of the fillets, and the draft angle should be carried in the general notes on the drawing.

8.8.2. Drawing 59, Link—Gear Door Operating.—Draw the machined part made from the forging in Exercise 8.8.1, as shown in Fig. 8.33.

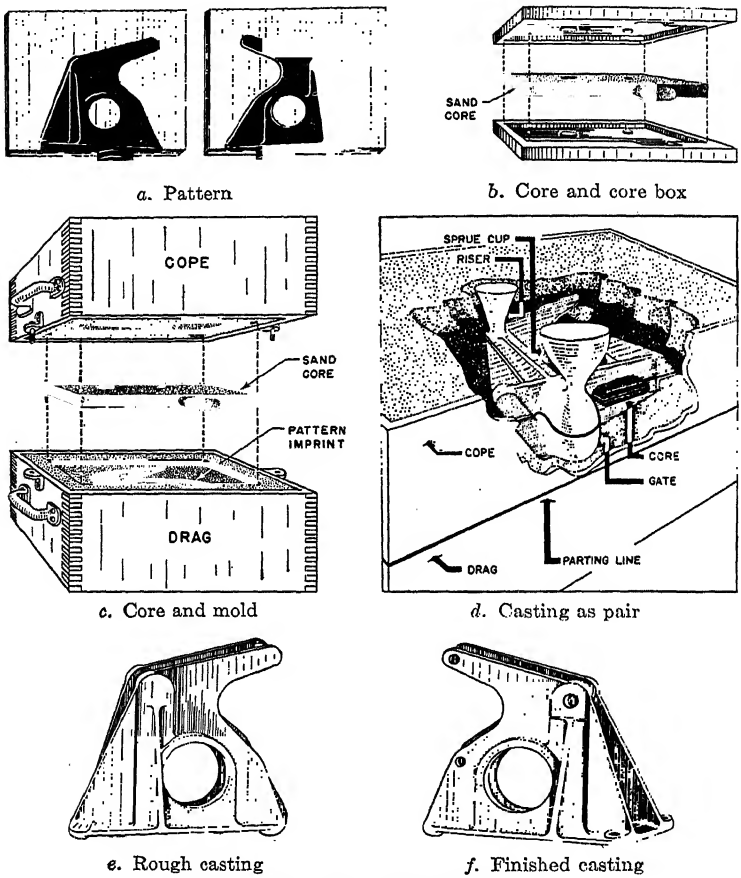


FIG. 8.34.—Sand-casting process.

8.9. Castings and Moldings.—Casting is the process of pouring molten metal into a mold or hollow of the required shape, so that, when the metal cools and hardens, it forms an irregular-shaped object. In sand casting, a wood pattern, shaped like the finished object but slightly larger, is placed in a split box,

and moist molding sand is packed tightly around it. The box filled with sand is split at the parting plane, exposing the pattern which, when removed, leaves an impression in the sand. The two halves of the box are then put together, and molten metal is poured into the impression through channels previously prepared in the sand (see Fig. 8.34). When cool, the casting is removed from the sand, and the excess metal from the channel

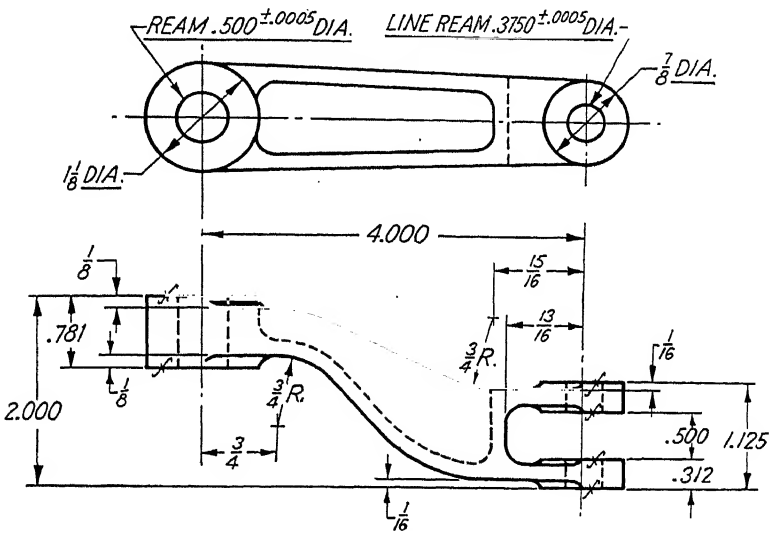


FIG. 8.35.—Arm—nose gear door operating.

is removed from the casting. The pattern for the casting is made slightly larger than the casting so that, as the metal cools, the casting will shrink to the right size. Sand cores are used in sand casting to form interior shapes and cavities in the casting, which cannot be incorporated in the pattern. The sand cores are formed in the core box, then removed, and hardened by heating. They can be used only once, since they must be knocked out of the casting after it is removed from the sand.

Sand-castings may be made in very complicated shapes and are cheap due to the low cost both of the pattern and the actual casting process. Cast surfaces are rough from the imprint of the grains of the casting sand and require some machining to finish them. Their size and shape vary more than do forgings, and they are not so strong as forgings because of weakness of the

casting material and air holes in the castings. Sharp interior corners are always filleted to permit smooth flow of the casting material; the fillet radius is usually called for in a general note together with the nominal web thickness. Sand-casting fillets have a minimum radius of $3/16$ in. and a minimum web thickness of $5/32$ in. The drawing calls for all finishing operations, such as drilling holes, spot-facing around holes (to make a flat surface for nuts or boltheads), disk grinding (to produce flat surfaces), machining of slots, etc. The patternmaker allows additional material where the finishing operation requires it. All surfaces, such as webs and fillets, which do not have to fit other parts remain in the rough, "as cast" condition. Figure 8.35 shows typical practice in drawing castings.

Exercises

8.9.1. Drawing 60, Arm—Nose Gear Door Operating.—Draw the views of the sand-casting shown in Fig. 8.35, full size and, in addition, show a section through the channeled part of the arm. The drawing should carry general notes that all fillets are $3/16$ in. in radius, all webs are $5/32$ in. thick, and the $\checkmark$ symbol indicates smooth machine finish.

8.9.2. Drawing 61.—Draw the part shown in Fig. 8.33 as a sand-casting by omitting the draft. All other dimensions and notes and the drawing title remain identical.

Permanent mold castings make use of a steel mold into which the molten metal is poured instead of the hollow in the sand, left by the sand-casting pattern (see Fig. 8.36). Since the surface of the hollowed-out area of the steel mold is very smooth, the casting thus produced is quite smooth and uniform in size, is made to much closer tolerances, and requires less machining than a sand-casting. The saving in machine time is offset by the rather high cost of the mold unless considerable quantities are used. Die castings are similar to permanent mold castings except that the molten metal is forced under pressure into the steel die or mold, producing an even more smooth and uniform casting than the permanent mold does. Die and casting costs are higher, however, and require considerable quantities to offset savings in machining time.

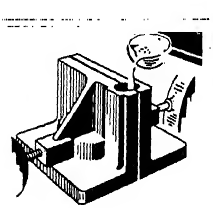


FIG. 8.36.—Permanent mold casting.

Various nonmetallic substances, such as rubber, plastics, and Bakelite, are molded into shapes by pouring or compressing them in dies under heat and pressure. Knobs, window and

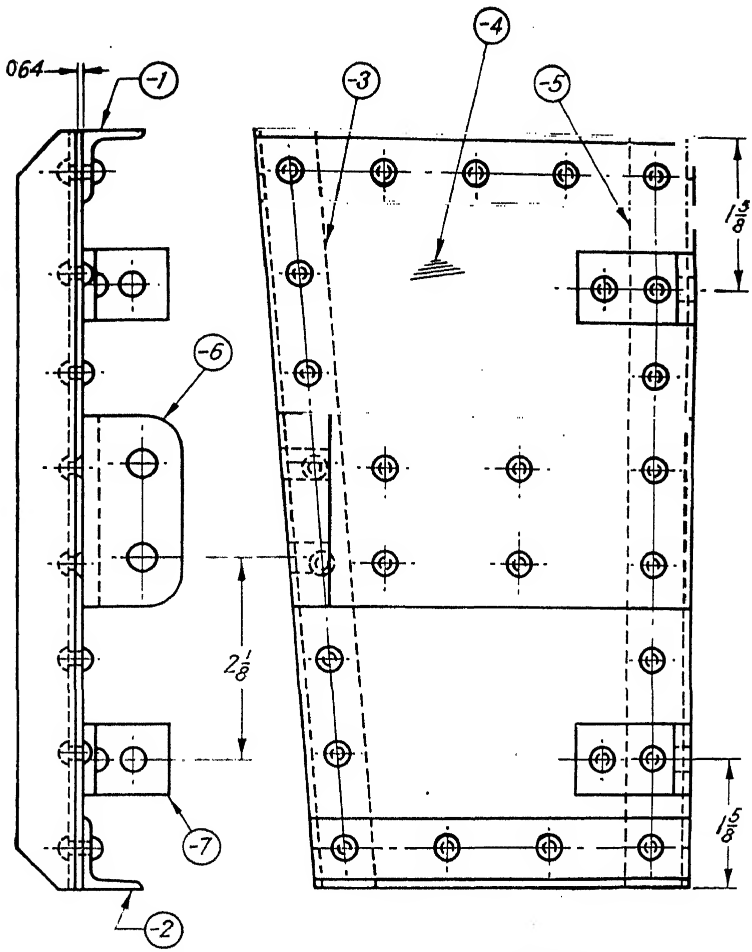


Fig. 8.37.—Support assembly for pilot's seat.

door sealing rings, flexible joints in air pipes for heating, ventilating, and carburetor air supply are produced by this process.

8.10. Wood and Cloth Parts.—The use of wood and cloth in airplane construction is usually confined to interior finishing, such as inside doors, tables, benches, floors, linings, dust covers

around landing gears, etc., and to coverings of movable control surfaces: ailerons, elevators, and rudders. Plywood is commonly used for wood construction due to its lightness, strength, and resistance to splitting. Nails, wood screws, and gluing are employed for joining wood parts. As a rule, engineering drawings do not go into great detail with wood objects but show basic outline dimensions and critical details, leaving general details of construction to the wood shop. Cloth parts are drawn similarly sketchy in detail, leaving the fitting of the cloth parts to the fabrication department. This is expedient, since cloth stretches to such an extent that any attempt to draw the exact shape of the material would in most cases result in a finished

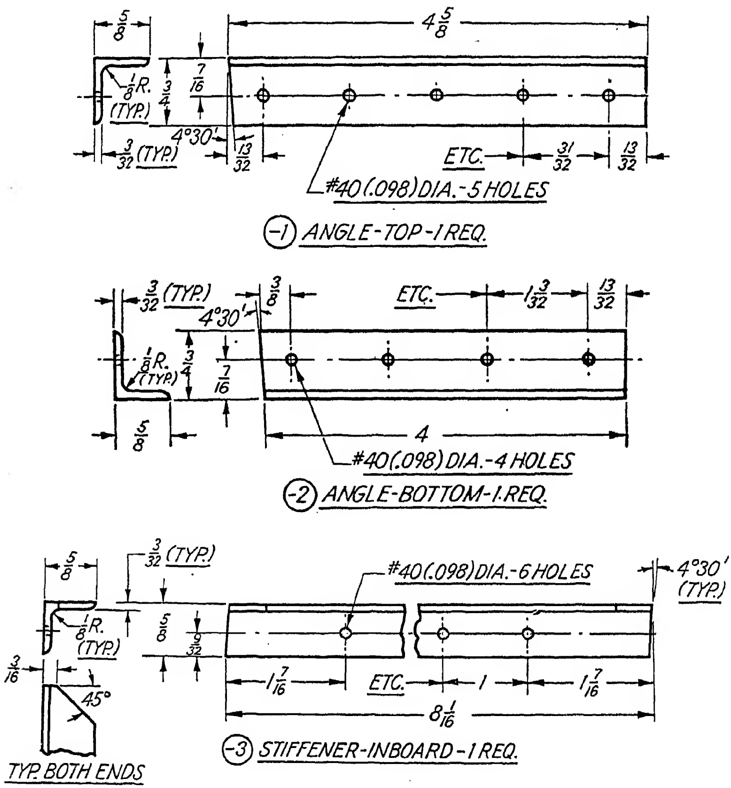
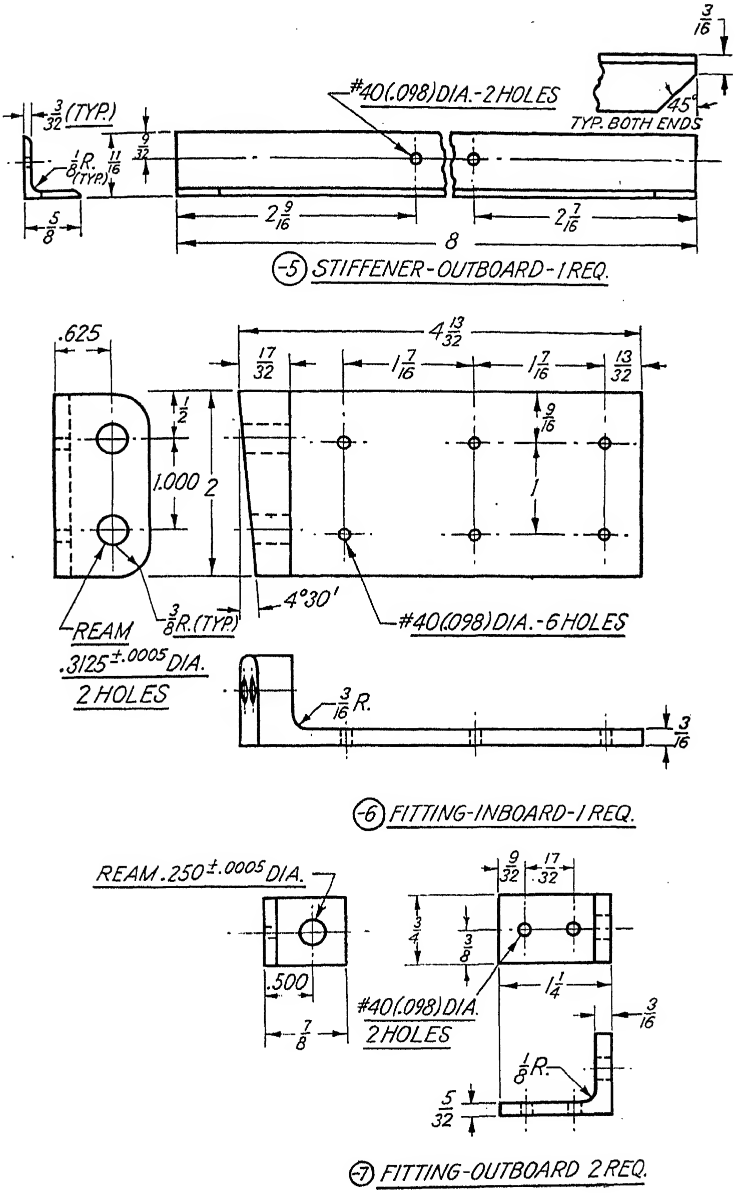


FIG. 8.38.—Details—



pilot's seat support.

product that does not fit. Drawings of cloth parts should endeavor to show how the parts look when installed on the airplane.

8.11. Assembly Drawings.—The building of an airplane consists of fabricating small parts or details, putting details together to form assemblies, combining assemblies to form larger assemblies, etc., until all parts required to form the complete airplane have been assembled. Because of the large size of assemblies, they are often drawn to reduced scale, such as half size, quarter size, or eighth size. Reduced scale drawings show very little detail, so full size views are taken of areas which require explanation on the drawing. In planning a series of detail drawings that can be combined into an assembly drawing, every effort should be made to show as much as possible on the detail drawings rather than on the assembly drawing. Detail parts are often piloted, or drilled, with undersized holes, so that on the assembly the pilot holes may be drilled out full size and through the parts to be attached, and rivets or screws may be inserted without requiring any dimensions to locate them. Dimensions on detail drawings should not be duplicated on assembly drawings; the assembly drawing should carry only those dimensions that are necessary to locate the details with respect to each other. In some cases, the assembly drawing serves as a picture to illustrate the arrangement of the details and of the attaching parts.

Exercises

8.11.1. Drawing 62, Details—Pilot's Seat Support.—Figure 8.37 shows an assembly drawing, and Fig. 8.38 shows the detail parts which make up the assembly. Draw the details shown in Fig. 8.38, full size. The encircled numbers identify the parts for use on the assembly drawing.

8.11.2. Drawing 63, Support Assembly—Pilot's Seat.—Draw the assembly consisting of the details of Exercise 8.11.1, as shown in Fig. 8.37. The only dimensions required are those necessary to locate the parts with respect to each other on assembly. The .064 in. thick panel is not separately detailed, since the other details determine its shape. The assembly drawing should carry the following general notes:

"Drill #30 (.128) dia. for all rivets"
"C'sink 100° × .248 dia. for all flush rivets"
"1/8 dia. round head rivets 25 req."
"1/8 dia. × 100° flush head rivets 2 req."

CHAPTER 9

DESCRIPTIVE GEOMETRY

9.1. Descriptive Geometry and Drawing.—Descriptive geometry is the branch of mathematics devoted to the representation of geometric figures with particular reference to their projection or manipulation. Much of the previous discussion concerning the drawing representation of an object falls within the scope of descriptive geometry. The more complicated manipulations of points, lines, planes, and solids, by which these figures are represented in usable and understandable fashion on a drawing, will be considered in this chapter. The material presented includes only the elementary and basic phases of descriptive geometry. The application of these principles will enable the draftsman to solve the drawing problems which are usually encountered and will assist him in obtaining a solution in the minimum time, avoiding costly trial-and-error methods.

9.2. Locating Points in Views.—A point is located in space by finding its distances from three planes, each perpendicular to the other two. A point inside a rectangular box is fixed if the following three dimensions taken from the sides of the box are known:

1. The distance above the bottom of the box or the height dimension.
2. The distance to the left of the side of the box or the width dimension.
3. The distance in back of the front of the box or the depth dimension.

The bottom, front, and side of the box correspond to three planes, each perpendicular to the other two. The three dimensions—height, width, and depth—are each perpendicular to the other two.

In orthographic projection, two views are required to locate a point in space, since any one view gives only two of the three required dimensions. If a point is shown in the front and side

views of an object, the front view shows the height dimension and the width dimension of the point, the side view repeats the height dimension and in addition shows the depth dimension of the point. The height, width, and depth dimensions of the point are measured from planes perpendicular to each other, which appear as straight perpendicular lines in the views, since they are perpendicular to the plane of the paper. The planes

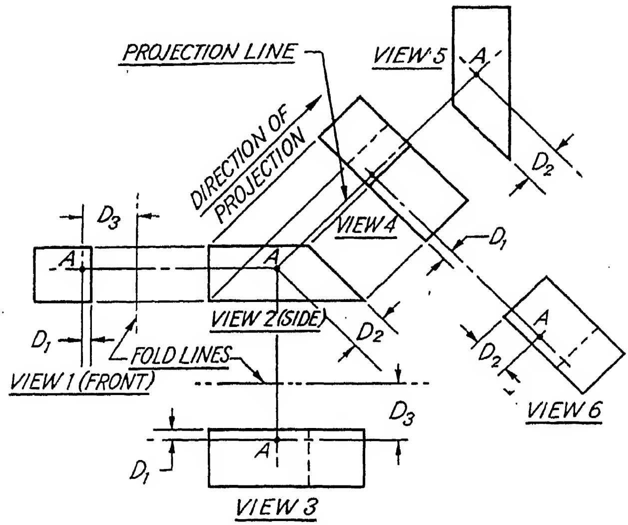


FIG. 9.1.—Projecting a point.

from which the height, width, and depth dimensions are taken may be either flat surfaces of the object in which the point is located or they may be imaginary planes located at fixed distances with respect to the object.

In establishing a new view of a point or an object, the direction of projection must be determined. The *direction of projection* is represented by a line in the direction in which the observer would look at the old view to see the new view, but it is directed away from the old view toward the new view (see Fig. 9.1). The direction of projection of a side view from a front view would be a line parallel to the bottom of the paper and pointing toward the side view. A point is located in a new view by drawing a *projection line* parallel to the direction of projection from the point in the old view to the new view.

If a point is located in a front view giving the height and width dimensions and a side view giving the height and depth dimensions, the point may be located in a new top view projected vertically from the front view. A vertical *projection line* is drawn upward from the point in the front view, since the *direction of projection* of the new view is upward. To establish the depth of the point along the projection line, the plane representing the front surface of the object must be located in the top view and will appear as a line perpendicular to the direction of projection. The depth dimension of the side view may then be measured upward from the line representing the front surface in the top view and along the projection line of the point, thus establishing the width and depth of the point in the top view.

A point is located in a new view by two offset distances or dimensions, at right angles to each other. One of these offsets is determined by the projection line from the point in the previous view, this projection line being parallel to the *direction of projection*. The other offset is measured the same distance along the projection line from a line or surface perpendicular to the projection line, as the point is located from the corresponding line or surface in any other view projected from the previous view. It will be observed that the corresponding line or surface is also perpendicular to the direction of projection of the other view.

Figure 9.1 shows the projection of a point, A, located in the front and side views of a block, to four auxiliary views of the block. Point A is first projected from view 2 to views 3 and 4 by means of projection lines parallel to the direction of projection. The location of point A along the projection lines in views 3 and 4 requires the selection of lines perpendicular to the direction of projection in these views, corresponding to a line perpendicular to the direction of projection in view 1. The fold lines located equally distant from the right side of view 1 and from the top side of view 3 could be used. Since point A is located a distance D_3 from the fold line of view 1, a distance equal to D_3 is measured along the projection line from the fold line of view 3 to locate point A in that view. The fold lines represent the lines about which views 1 and 3 could be folded down to obtain their true relation to the block depicted therein, like the hinge lines used in unfolding the glass walled box shown in Fig. 4.18.

However, since the direction of projection is usually perpendicular to a line or a surface of an object, it is more convenient

to use that line or surface. Point A is located in views 3 and 4 a distance D_1 from the side nearest to view 2, which side is observed to be perpendicular to the direction of projection of views 3 and 4. Distance D_1 was obtained from view 1, which is also a projection of view 2, and was measured from the corresponding side of the block nearest to view 2, which side is also observed to be perpendicular to the direction of projection of view 1. Point A is located in views 5 and 6 by projecting it from view 4 parallel to the direction of projection of views 5 and 6 and by measuring inside the block in views 5 and 6 a distance D_2 equal to the distance D_2 in view 2, and parallel to the direction of projection of view 2 from view 4. It should be noted that distance D_2 in view 2 was measured from a surface perpendicular to the direction of projection of view 4 and that distance D_2 was measured from the same sloping surface in views 2, 5, and 6. In projecting points from circular objects, such as holes and cylinders, the center lines of the circular objects may be used as reference planes from which to take measurements parallel to the direction of projection. In Sec. 5.6, the cylindrical intersections were developed by projecting the series of points formed by the intersection of the cylinders from the auxiliary views to the main view.

Exercise

9.2.1. Draw the views shown in Fig. 9.1. Locate three other points in views 1 and 2, label them B, C, and D, and project them to views 3, 4, 5, and 6. The views of the block should be drawn approximately twice the size shown in Fig. 9.1.

9.3. Locating Lines in Views.—A straight line always appears as a straight line in any view except when the view is looking down the length of the line, in which case the line appears as a point. In any view showing a line out of the plane of the paper, the line always appears shorter than its true length. This may be illustrated by revolving a straight knitting needle under a light and observing how the length of its shadow changes, the shadow corresponding to the view of the line.

Since two points determine a straight line, that line may be projected to any view by projecting two points on the line from two adjacent views to the new view and by connecting these points in the new view by a straight line. In Fig. 9.2, views 1

and 2 are the front and side views of a straight line the end points of which are labeled A and B. The line is established in views 3 and 4 by projecting points A and B to these views and connecting them by a straight line. It should be noted that, since there are no surfaces perpendicular to the direction of projection, center lines perpendicular to the direction of projection were established through point B from which to measure the distance D that locates point A in views 3 and 4. The method of projecting the end points A and B in Fig. 9.2 is identical to the procedure followed in Fig. 9.1.

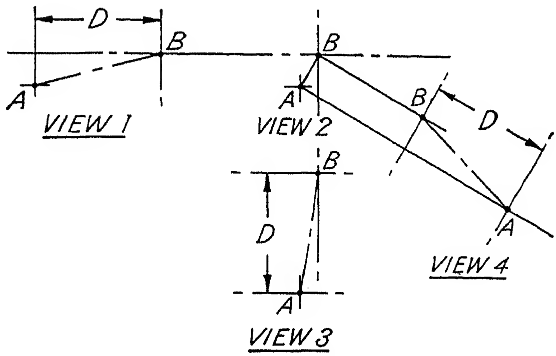


FIG. 9.2.—Projecting a line.

Exercise

9.3.1. In Exercise 9.2.1, connect points B and D with a straight line in view 1. Also, connect points B and D with a straight line in view 2. Connect the projections of points B and D with a straight line in view 3, and proceed successively in views 4, 5, and 6. By this procedure, the line BD has been projected into each view progressively.

9.4. Locating Planes and Solids in Views.—A plane is determined by any three points or by two intersecting or parallel lines. Planes are quite frequently rectangles which are determined and bounded by four points and four lines. Solids are located and bounded by planes, lines, and points. Planes and solids may, therefore, be projected to any view by projecting points and lines of the plane or solid to the required view. Figure 9.3 shows the projection of a block from the top and the front views to a side and an auxiliary view. The end which is cut

off square is used as the line perpendicular to the direction of projection of the top, the side, and the auxiliary views from which points and lines are located during projection.

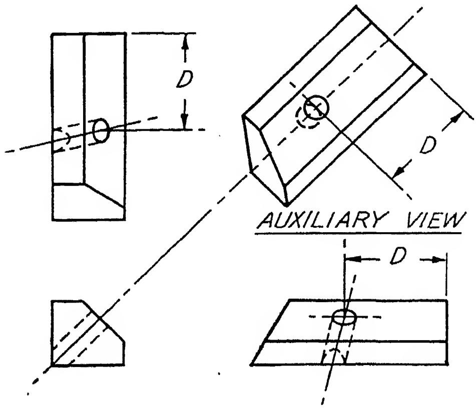


Fig. 9.3.—Projecting a solid.

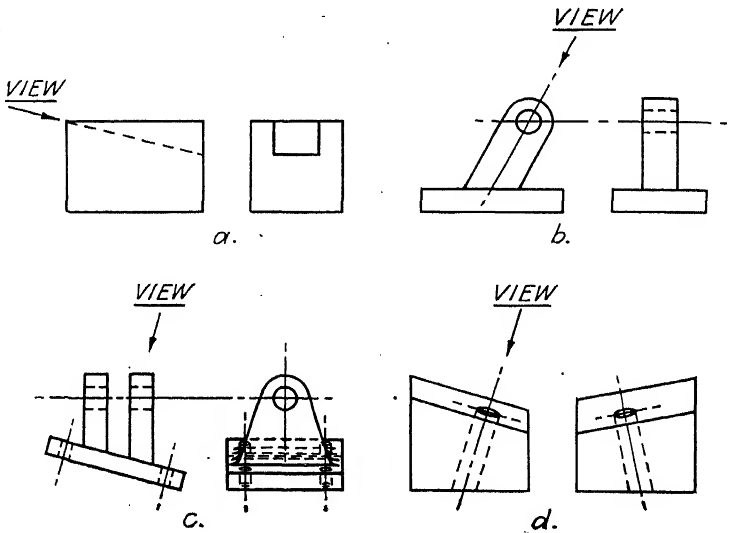


Fig. 9.4.—Projection exercises.

In projecting lines joined by arcs, such as two surfaces filleted together, the lines or planes are extended to the point of inter-

section, then the fillet is laid in, and the unwanted part of the line beyond the fillet is erased.

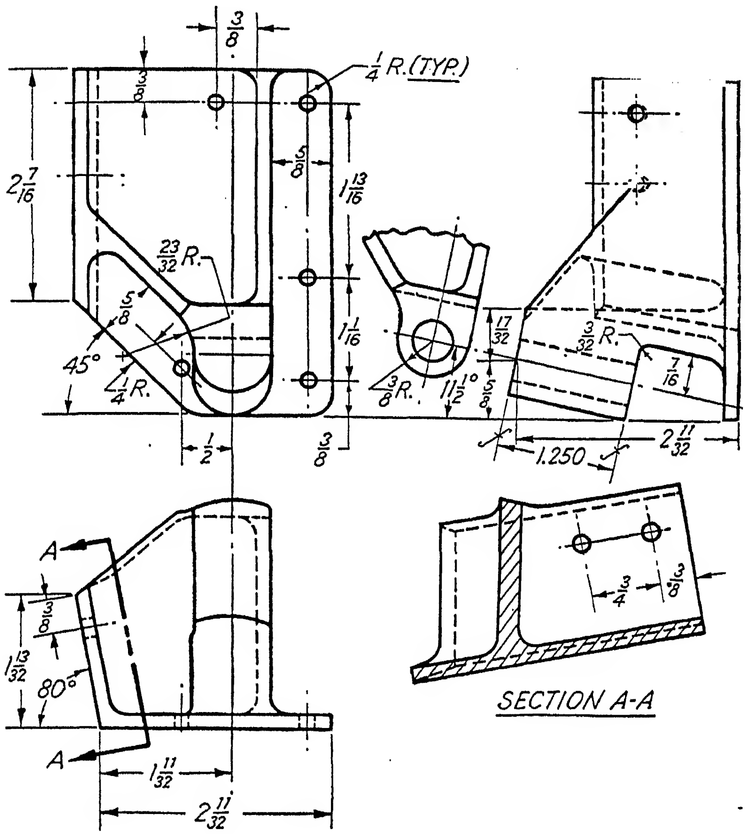


FIG. 9.5.—Casting—platform latch.

Exercises

9.4.1. Draw the views indicated in Fig. 9.4. The size of the blocks as drawn should be determined by dimensions four times those scaled from the sketches.

9.4.2. Drawing 64, Casting—Platform Latch.—Lay out the casting shown in Fig. 9.5 on a standard drawing form, completing the views shown. All webs are 5/32 in. thick and all fillets are 3/16 in. radius; the small holes are 3/16 in. in diameter, and the large hole is 7/16 in. in diameter. In starting, show only simple lines and planes in each view, and then develop the more complicated contours from the views that show these contours simply. Do not try to complete one view first, but develop all views together, work-

ing back and forth among the views. The views may be rearranged on the drawing as required.

9.4.3. Drawing 65, Lug—Tension Anchor.—Proceed as in Exercise 9.4.2. Two views in Fig. 9.6 show the block simply; the other three show the lug simply. Select points around the curved surface of the lug to project it to the simple views of the block, after projecting the block into the three views showing the lug simply. It is suggested that, to prevent confusion,

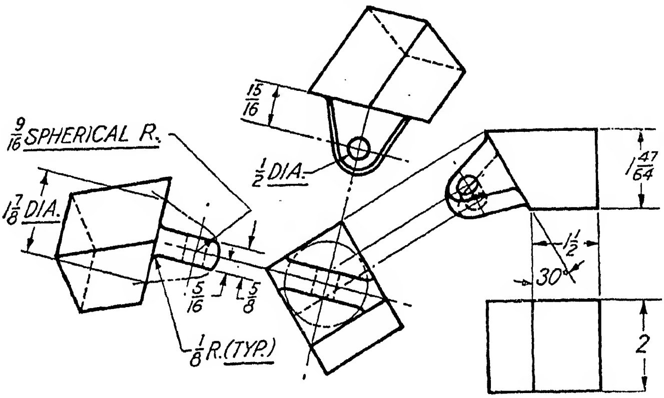


Fig. 9.6.—Lug—tension anchor.

surfaces such as one side of the block or one face of the lug be projected into all complicated views before beginning the projection of the next surface. This is an exercise in projection. To save drafting time, in actual drafting practice the detailed projection of the block and the lug out of the plane of the paper would be broken off or would be shown incompletely.

9.5. True View of a Line.—In Chap. 7, a method of calculating the exact length of a line was discussed. To show a line in its true length on a drawing, the line must be shown in the plane of the paper. Any straight line can be shown in the plane of the paper by a single auxiliary view, taken at right angles to any view of the line.

Figure 9.7 shows a top view and a front view of straight line AB, in which point B has been located by depth, width, and height dimensions from planes at right angles to each other and passing through point A. The top view shows the depth dimension of point B as L_1 and the width dimension as L_2. The front view repeats the width dimension of point B, and in addition shows the height dimension as L_3. To find the true length of line AB, an auxiliary view has been projected from the front view, the direction of projection being perpendicular to the projected

line AB in the front view. Point A is located in the auxiliary view on its projection line, and a line is drawn perpendicular to this projection line. Point B is located in the auxiliary view by measuring the depth dimension, L_1, from the perpendicular line through point A and along the projection line of point B. It should be noted that the depth dimension L_1, locating point B in the auxiliary view, is measured *toward* the front view, since

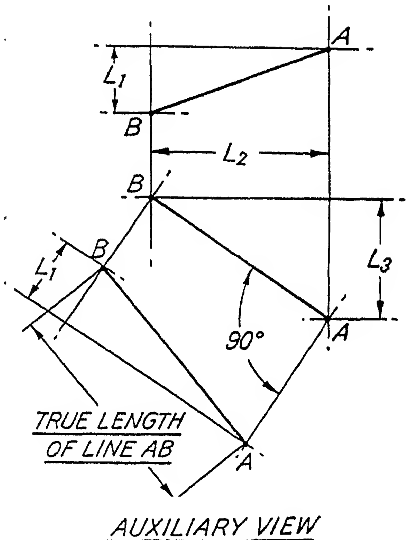


FIG. 9.7.—True view of a line.

the same depth dimension in the top view was measured toward the front view. The straight line connecting points A and B in the auxiliary view represents the true length of line AB, and this line lies in the plane of the paper.

Exercises

9.5.1. Project the line in Fig. 9.7 from the top view to a true view if $L_1 = 3\frac{1}{8}$ in., $L_2 = 7\frac{15}{16}$ in., and $L_3 = 4\frac{7}{32}$ in. Measure the length, and check it by calculation.

9.5.2. Lay out the two views of the landing-gear truss center lines shown in Fig. 7.27, $\frac{1}{16}$ size. Project the center lines not already in the plane of the paper into the plane of the paper, and measure the true length of the lines. Does the length of the projected line agree with one-sixteenth of the calculated length?

9.6. True View of a Plane.—A true view of a plane is one in which the plane lies in the plane of the paper.

Case 1.—If one of the given views shows the plane on edge so that it appears as a single straight line, the true view is obtained by projecting a view perpendicular to that straight

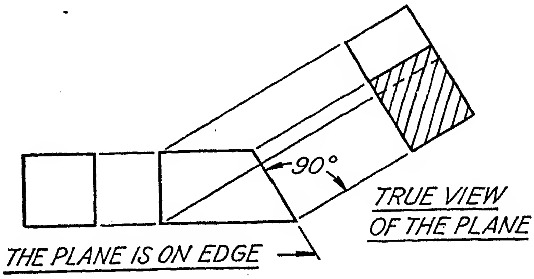


FIG. 9.8.—True view of a plane normal to the paper.

line. Figure 9.8 shows a front and a side view of a block. The right-hand end of the block in the side view is a sloping plane perpendicular to the plane of the paper, therefore appearing as a straight line. A true view of the sloping plane is obtained by

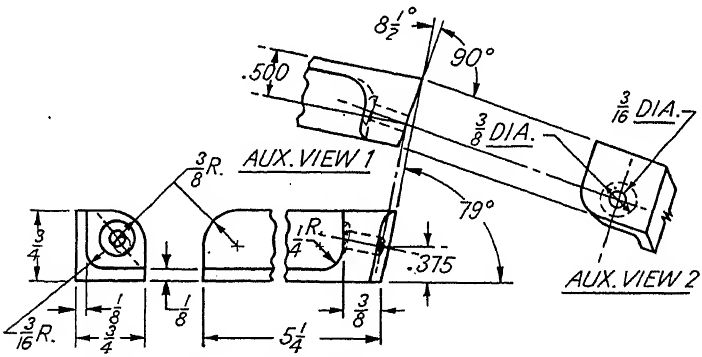


FIG. 9.9.—True view of a plane not normal to the paper.

projecting an auxiliary view of the block, perpendicular to the sloping plane of the side view. The sloping plane, as indicated by the cross-hatched area of the block in the auxiliary view, is in the plane of the paper.

Case 2.—If the plane is not shown normal to the plane of the paper in any view, but one view contains a line lying both in the plane of the paper and on the subject plane, a view along that

line is projected. The line appears as a point, and the plane appears as a line in this first auxiliary view. A second auxiliary view is then projected perpendicular to the subject plane in the first auxiliary view, which produces a true view of the given plane in the plane of the paper. Figure 9.9 shows a front and a side view of a fitting in which the right-hand end surface is not perpendicular to the plane of the paper in the side view. The far edge of the canted surface is a line in the plane of the paper, sloping 79 deg. from the horizontal. Auxiliary view 1 is

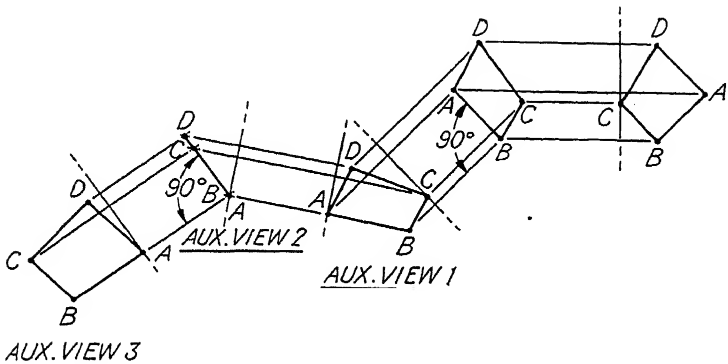


FIG. 9.10.—True view of a nonrectangular plane.

projected in the direction of this 79-deg. line, producing a view looking along the length of this line and showing the cant plane perpendicular to the plane of the paper. Following the procedure of Case 1, auxiliary view 2 is projected perpendicular to the line representing the canted plane in auxiliary view 1, thus producing a true view of the canted plane, since in auxiliary view 2 the canted plane lies in the plane of the paper.

Case 3.—If no line in the given plane lies in the plane of the paper, three auxiliary views are required. The first auxiliary view is projected to obtain one line of the given plane in the plane of the paper. The second auxiliary view is projected from the first auxiliary view to rotate this line perpendicular to the plane of the paper, thereby resulting in projecting the given plane perpendicular to the plane of the paper. The third auxiliary view is then projected perpendicular to the given plane in the second auxiliary view, resulting in a true projection of the plane. Figure 9.10 shows the front and side views of a plane bounded by

the four lines, *AB*, *BC*, *CD*, and *DA*, none of which lies in the plane of the paper in either view. Auxiliary views 1, 2, and 3 are projected successively, starting from the front view, to obtain a true view of plane *ABCD*. Auxiliary view 1 is projected perpendicular to line *AB* in the front view and shows the true length of line *AB*. Auxiliary view 2 is projected along line *AB* from auxiliary view 1 and shows line *AB* as a point and plane *ABCD* as a line. Auxiliary view 3 is projected perpendicular to plane *ABCD* in auxiliary view 2 and shows plane *ABCD* in true view, *i.e.*, in the plane of the paper.

Case 4.—If a line is known to be perpendicular to a plane, a true view of the plane may be obtained by projecting a true view of the perpendicular line, and from this view projecting along the line to a view showing the line as a point and also showing the plane in true view. In Fig. 9.9, the hole center line is perpendicular to the canted plane. Auxiliary view 1 shows the true length of the center line and the canted plane perpendicular to the plane of the paper. Auxiliary view 2 shows the center line as a point and the canted plane, therefore, in the plane of the paper.

The true view of a plane is required to show dimensions lying in that plane, both linear and angular, such as the shape and the size of the part of the object in that plane, the arrangement of holes in the plane, and the angular measurements for hole spacing or for the oblique edges of the surface. The plane must always be located by angles and offsets with respect to the rest of the object. In Fig. 9.9, the 79-deg. angle locates the direction of projection of the first auxiliary view and the 8½-deg. angle locates the slope of the surface with relation to the direction of projection. These two angles determine the direction of the plane. The 5¼, .375, and .500 in. dimensions locate the intersection of the hole center line with the sloping plane in relation to the rest of the object. The sloping plane is, therefore, located as passing through the point where the hole center intersects the plane and has a slope defined by the two angles. Any alternate point on the plane could have been located by offsets in order to determine the relation of the plane to the rest of the fitting.

The true angle between a line and a plane is defined as the angle formed by the line and its perpendicular projection upon

the plane. To obtain a true view of this angle, the plane and the line are projected until the plane is shown in true projection, *i.e.*, in the plane of the paper. Another view is projected perpendicular to the projection of the line in this true view of the given plane. This latter projection shows the plane to be perpendicular to the plane of the paper, and shows the line in the plane of the paper, thus giving the true angle between the line and the given plane. Figure 9.11 shows an engine-mount fitting, which connects a brace tube to a firewall. In the view

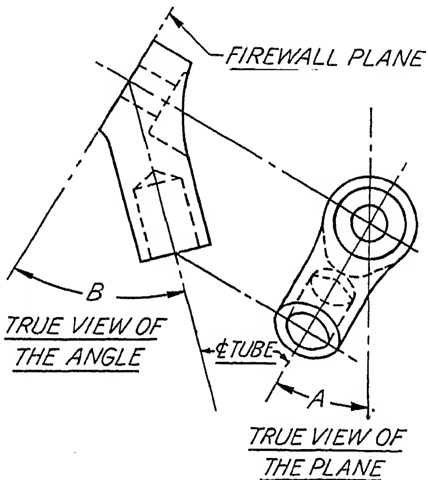


FIG. 9.11.—True view of the angle between a line and a plane.

showing the firewall plane in the plane of the paper, angle A indicates the direction that the projection of the tube center line makes with the true vertical. In the view projected perpendicular to the projection of the tube center line in the right-hand view, angle B is the true angle between the tube center line and the firewall plane. In making a detail drawing of this fitting, the two views shown and a third view looking down the center line of the tube would be used. These views would be drawn so that the tube center line would lie on either a vertical or horizontal line, since detail drawings do not necessarily show the parts in the same position that they would assume when assembled on the airplane.

The true angle between two lines is found by obtaining a true view of the plane that contains both lines. In Fig. 9.12,

next view is then projected along the intersection line, producing a view showing the intersection line perpendicular to the plane of the paper. This last projection places both planes perpendicular to the plane of the paper, since the intersection line lies in both planes and since, if any line in a plane is perpendicular to the plane of the paper, the plane is perpendicular to the plane of the paper.

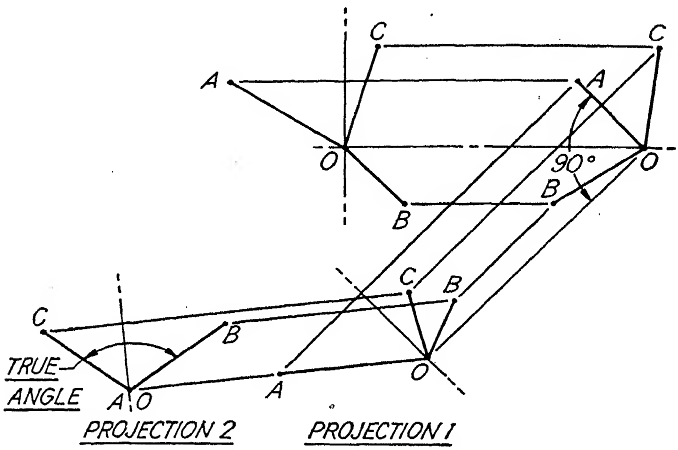


FIG. 9.15.—True angle between planes.

Figure 9.15 shows a front and a side view of two planes. One plane is determined by the lines AO and OB, the other plane is determined by the lines AO and OC. The two planes intersect in line AO, which of necessity lies in both plane BOA and plane COA. Projection 1 is taken perpendicular to line AO in the side view to obtain its true length. Projection 2 is taken along line AO in projection 1 to obtain line AO perpendicular to the plane of the paper, thus showing both plane BOA and plane COA perpendicular to the plane of the paper and the true angle between the planes. A true view of either of these planes could be obtained by projecting a perpendicular to line CO or BO in projection 2. Usually the projection of true angles, planes, and lines is much more simple than that shown in Fig. 9.15, since the original views are chosen with as many lines and planes as possible perpendicular or parallel to the plane of the paper, thus eliminating many steps to get lines and planes into these positions. From the above discussion, it is obvious why it was

lines AO, BO, and CO; (b) between each line and the plane formed by the other two lines.

9.6.4. Project true views of the end planes of the object shown in Fig. 9.14. In the construction use dimensions twice as large as those scaled from the sketch.

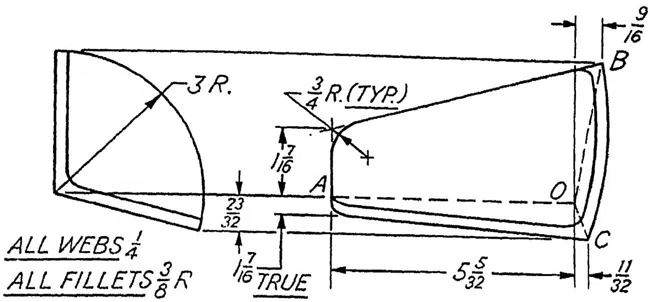


Fig. 9.13.—Fitting—corner seal.

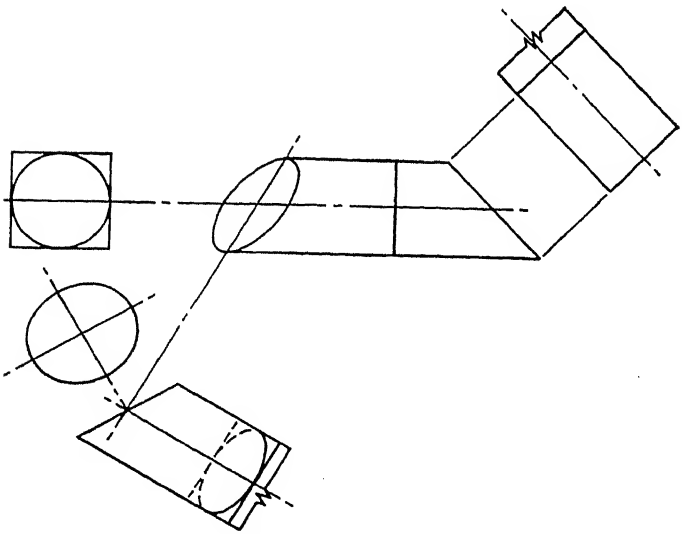


Fig. 9.14.—Oblique planes.

9.7. True Angle between Planes.—The true angle formed by two intersecting planes is found in the view showing both planes perpendicular to the plane of the paper. Since two planes intersect in a straight line, the view of the true angle between two planes is obtained by first projecting the line formed by the intersection of the two planes into the plane of the paper. The

next view is then projected along the intersection line, producing a view showing the intersection line perpendicular to the plane of the paper. This last projection places both planes perpendicular to the plane of the paper, since the intersection line lies in both planes and since, if any line in a plane is perpendicular to the plane of the paper, the plane is perpendicular to the plane of the paper.

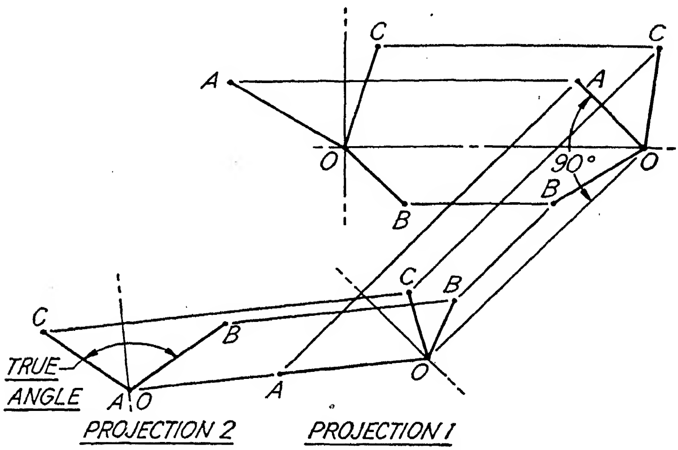


FIG. 9.15.—True angle between planes.

Figure 9.15 shows a front and a side view of two planes. One plane is determined by the lines AO and OB, the other plane is determined by the lines AO and OC. The two planes intersect in line AO, which of necessity lies in both plane BOA and plane COA. Projection 1 is taken perpendicular to line AO in the side view to obtain its true length. Projection 2 is taken along line AO in projection 1 to obtain line AO perpendicular to the plane of the paper, thus showing both plane BOA and plane COA perpendicular to the plane of the paper and the true angle between the planes. A true view of either of these planes could be obtained by projecting a perpendicular to line CO or BO in projection 2. Usually the projection of true angles, planes, and lines is much more simple than that shown in Fig. 9.15, since the original views are chosen with as many lines and planes as possible perpendicular or parallel to the plane of the paper, thus eliminating many steps to get lines and planes into these positions. From the above discussion, it is obvious why it was

stated in Chap. 4 that views should be selected with the main planes and lines parallel or perpendicular to the plane of the paper. The views are not only easier to understand, but require fewer auxiliary views to describe the object completely. Therefore, *detail parts are drawn in simple positions rather than in the position which they would occupy in the airplane.*

The simplest manner in which a drawing can show a machinist how to make a cut that is canted in two directions to the rest of the part is illustrated in Fig. 9.9. The line representing the intersection of the cant plane and the plane of the paper makes an angle of 79 deg. with one rectangular plane of the object. The next view is projected along this intersection line, showing both the cant plane and a second rectangular plane of the object perpendicular to the plane of the paper. In this latter view, the true angle between the cant plane and the second rectangular plane is shown and dimensioned as 8½ deg. In machining the part, the line dimensioned as 79 deg. is first placed flat and parallel to the machine's cutting surface. The surface of the part in the plane of the paper in the side view is then elevated 8½ deg. from the level position, rotating about the intersection line. The cut is then made, producing a surface at the required angle.

Exercises

9.7.1. In Fig. 9.13, project the three views which show the true angles between the three planes.

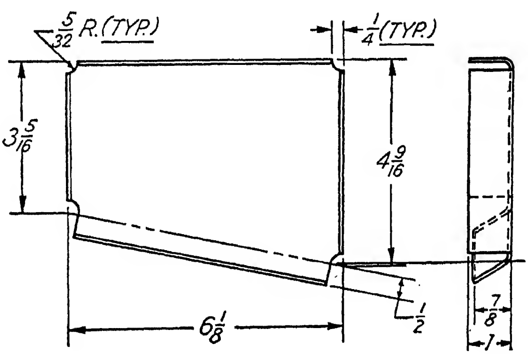


FIG. 9.16.—Stiffener—ventilating control.

NOTE.—One intervening view is required to show the true angle between the bottom and the end surfaces, since the intersection line does not lie in the plane of the paper.

9.7.2. Drawing 66, Stiffener—Ventilating Control.—Figure 9.16 shows the front and the side views of a bent-up sheet-metal stiffener, three flanges of which are perpendicular to the main surface of the part and to each other. The fourth flange is not perpendicular either to the main surface of the part or to the other flanges. This flange is located in Fig. 9.16 by dimensions which are not directly usable in the shop, it being necessary that the true angle between the flange and the main surface be given. Project the views which show this true angle and also the flange in the plane of the paper, dimensioning the angles. All bends are 3/16 in. in radius, and the material is .051 in. thick. Show only as much of the stiffener in the auxiliary

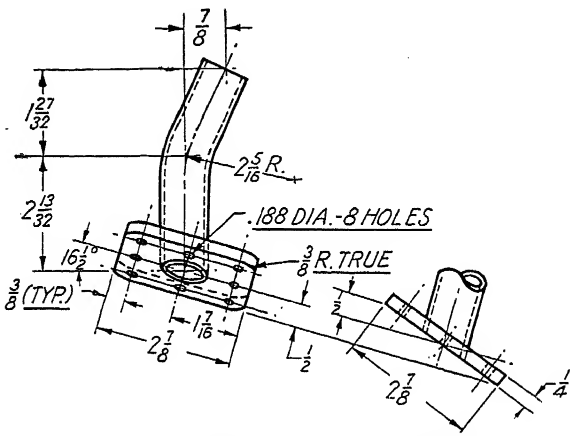


FIG. 9.17.—Fitting—oil tank connecting.

views as is necessary to identify the flange's relation to the rest of the object.

9.8. Problems.—In the following problems, the sketches provide sufficient dimensions for the draftsman to determine the projections. The views shown and the dimensions given are not necessarily in good form. The draftsman should select the views required and should replace the dimensions with angular dimensions calculated where possible and, if not possible, scaled from his own drawings.

9.8.1. Drawing 67, Fitting—Oil Tank Connecting.—On a standard drawing form show the views required completely to describe and dimension the fitting shown in Fig. 9.17. The tube has a 1 1/16 in. outside diameter and 1/16 in. wall thickness.

9.8.2. Drawing 68, Duct—Cold Air Inlet.—The duct shown in Fig. 9.18 should be drawn half size. The pipe is 1 1/2 in. in diameter, and the bends have 2 1/2 in. radii at the pipe center in true view. Both ends are cut off square with the center line of the pipe. The true views of the bends should be shown, as well as the angles of the projections and the bends, these angles being determined by the offsets of the center lines in the sketch.

9.8.3. Drawing 69, Brace—Compass Support.—Show and dimension the true angles of the bends in Fig. 9.19, all bends being $\frac{3}{16}$ in. in radius and the material being .064 in. thick. All flanges are 1 in. high.

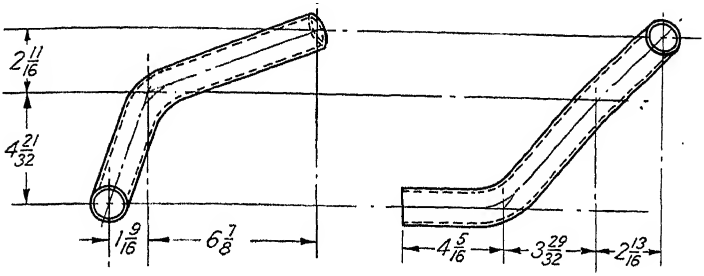


Fig. 9.18.—Duct—cold air inlet.

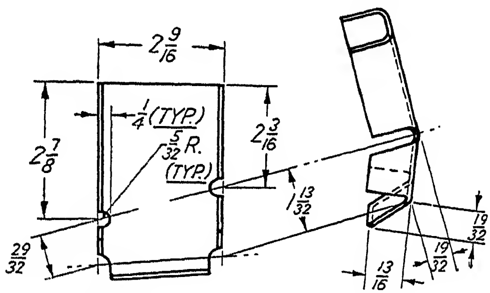


Fig. 9.19.—Brace—compass support.

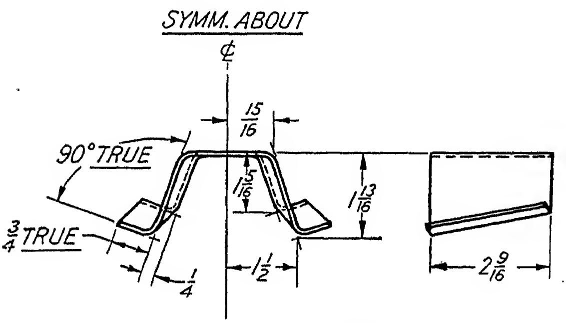


Fig. 9.20.—Bracket—heater attaching.

9.8.4. Drawing 70, Bracket—Heater Attaching.—Proceed as in Problem 9.8.3 in regard to Fig. 9.20.

9.8.5. Drawing 71, Fitting—Spar Reinforcing.—Show in Fig. 9.21 the true angle that the sloping surface of the fitting makes with the back of the fitting and the true view of this sloping surface. All webs are $\frac{1}{4}$ in. thick and all fillets are $\frac{3}{8}$ in. in radius.

9.8.6. Figure 9.22 shows a diagram of three engine-mount-brace tubes connecting the firewall with the ring upon which the engine is hung. (*a*) Project views showing the true angles between each pair of tubes at the firewall intersection. (*b*) Project views showing the true angle between

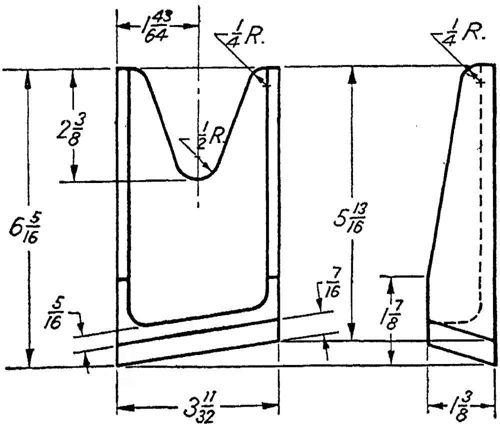


FIG. 9.21.—Fitting—spar reinforcing.

each tube and the engine-mount ring plane. (*c*) Calculate each angle shown in the views projected in (*a*) and (*b*). The angles determined are to be used in drawing the fittings to be detailed in Problems 9.8.7, 9.8.8, 9.8.9, and 9.8.10. Note that the true angles between each tube and the

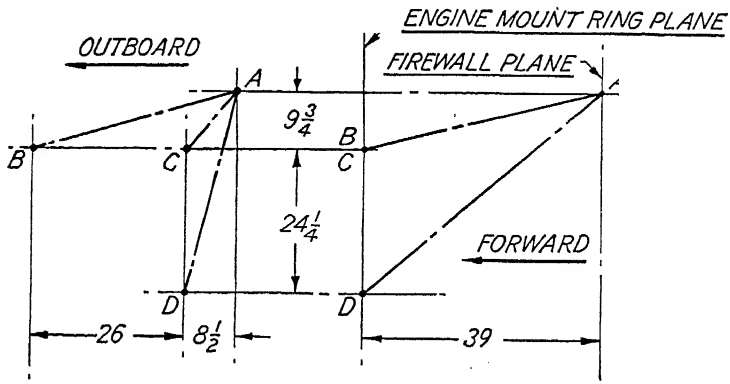


FIG. 9.22.—Engine mount diagram.

engine-mount-ring plane equal the corresponding angles between the tubes and the firewall plane. Why?

9.8.7. Drawing 72, Fitting—Engine Mount Forward Upper Outboard.—Draw the fitting shown in Fig. 9.23, using angles previously determined in

Problem 9.8.6 for point *B*. Use the fewest views possible, and dimension completely.

9.8.8. Drawing 73, Fitting—Engine Mount Forward Upper Inboard.—Draw the fitting shown in Fig. 9.24, using angles previously determined in

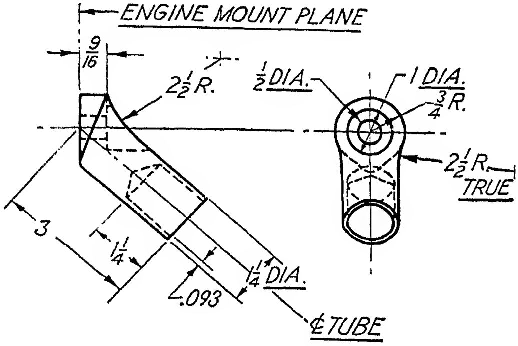


Fig. 9.23.—Fitting—engine mount forward upper outboard.

Problem 9.8.6 for point *C*. Use the fewest views possible, and dimension completely.

9.8.9. Drawing 74, Fitting—Engine Mount Forward Lower Inboard.—Draw the fitting shown in Fig. 9.23, using angles previously determined in Problem 9.8.6 for point *D*. Use the fewest views possible, and dimension completely.

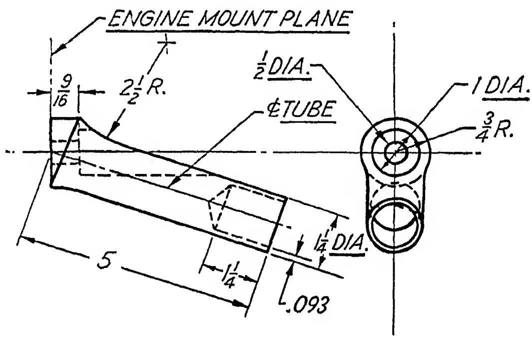


Fig. 9.24.—Fitting—engine mount forward upper inboard.

9.8.10. Drawing 75, Fitting—Engine Mount Aft Upper Inboard.—Draw the fitting shown in Fig. 9.25, using the angles previously determined in Problem 9.8.6 for point *A*. The main view should be taken with the firewall surface in the plane of the paper. From this view may be projected the views which will develop the true angles between each pair of tubes. Since no view in Fig. 9.25 shows the true length of the tubes, these true lengths

must be developed in auxiliary views and projected back to the main view. Each tube of 1¼ in. diameter is faired into the 1⅛-in.- radius base by the

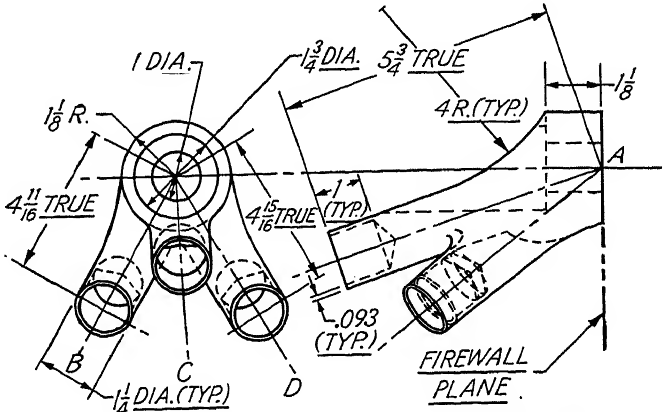


FIG. 9.25.—Fitting—engine mount aft upper inboard.

4 in. typical radius. The intersections of the tubes with each other are filleted in with a ¼ in. radius.

APPENDIX

A. DRAFTING AIDS

1. Drafting Machine.—There are many devices available to the draftsman which will simplify his work and increase his output. The most outstanding of these is the drafting machine, with which the average draftsman can increase his output by approximately one-fourth and do more accurate work with less effort. It combines the functions of the T square, triangles, 12-in. scale, and protractor in a single instrument (see Fig. *A*).

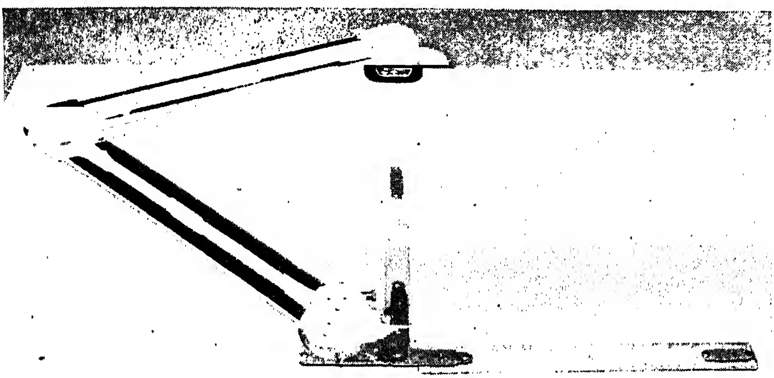


FIG. *A*.—Drafting machine.

The model illustrated consists of an anchor clamp and pulley, connected by two spacer arms and two flexible steel bands under tension through an elbow pulley to a drafting head (see Fig. *B*) in which are mounted combination scales and straightedges at right angles to each other. As the drafting head is moved around the drafting board, the arrangement of spacing bars and tension bands maintains the head and the scales exactly in parallel positions, permitting parallel lines to be drawn anywhere within a circle of approximately 4 ft. radius. Releasing a simple friction lock permits the grooved scale carrier to be

rotated with respect to the drafting head so that the scales may be adjusted to the lines of the drawing, after which the scale-carrier lock is again tightened. This procedure saves the time ordinarily consumed in adjusting the paper so that lines are perpendicular or parallel to the T square. The drafting head is also fitted with an angular scale or protractor and a vernier scale, which enables settings of the head to be adjusted to angles of 5 min. or $\frac{1}{12}$ deg. A second friction lock releases the part of

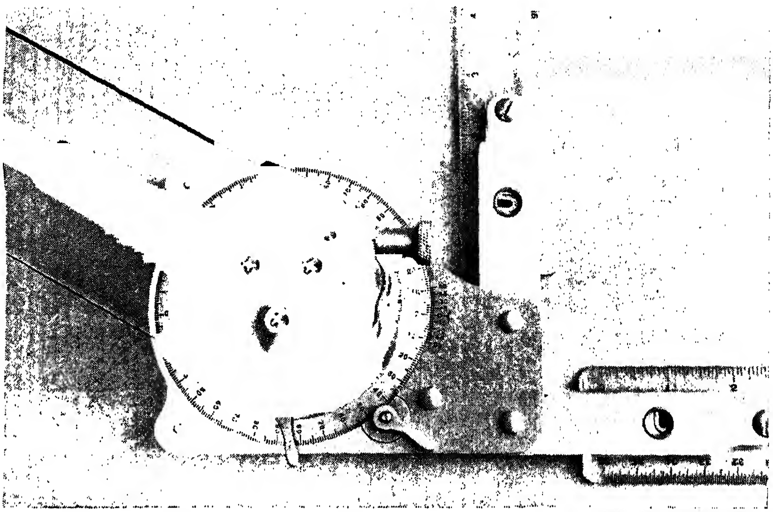


FIG. *B*.—Drafting machine head.

the head to which the scale carrier is attached from the part of the head containing the protractor, thus permitting the scales to be rotated through a definite angle and to be clamped at that angle. The angular scale also incorporates an indexing plate with slots at 0 deg., 15 deg., 30 deg., etc., around its circumference. A latching lever is provided that may be dropped into the indexing slots, thus positively fixing the scales at any one of the indexing plate angles. The latching lever is normally engaged in the 0-deg. slot; but if it is released and the head is rotated, the head may be returned exactly to its original position by dropping the latching lever into the 0-deg. slot again. The angles normally drawn by the 30–60-deg. and 45-deg. triangles may be set on the drafting machine by using the indexing plate

and the latching lever. The scales are usually ruled for full- and half-scale measurement on one edge and for quarter-scale measurement on the other. They may be easily detached from the scale carrier and reversed for different scale measurements.

The accuracy of the drafting machine is dependent upon its accurate adjustment, its proper use, and upon periodic checks of its accuracy. A suggested adjustment procedure is as follows:

1. With the anchor clamp secured to the drafting board, check that the tension bands are tight, that the drafting head does not have play, and that the scales lie flat on the drafting board and are firmly pressed into the grooves of the scale carrier. The scales may be made to lie flat by raising or lowering the adjustable skid buttons on the underneath side of the drafting head.

2. Lock the scale-carrier friction lock securely, release the angular scale friction lock, and drop the angular indexing plate locking lever into the 0-deg. angular setting slot. Draw a fine line along the entire length of the horizontal scale, using a hard pencil with an extremely fine point.

3. Release the angular indexing plate locking lever, rotate the head until the lever may be dropped into the 180-deg. slot, and check that the scale edge again exactly coincides with the line previously drawn. If it does not, the machine should be adjusted by the factory.

4. Rotate the drafting head back to the 0 position, lock it, and remove the horizontal scale from the groove in the scale carrier and enter the opposite end of the scale into the groove. Check the scale in this new position against the line. If they do not coincide exactly, loosen the screw in the slotted scale-engaging plate, rotate the scale until exact coincidence is obtained, tighten the screw, and check the coincidence again.

5. Rotate the drafting head to the 90-deg. position, and drop the angular indexing locking lever into the slot. Adjust the second scale to exact coincidence with the check line.

6. Reverse the second scale, and adjust to the check line in this position.

7. Draw a vertical line with the first scale, leaving the drafting head locked in the 90-deg. position. Rotate the head back to the zero position, lock it there, and see whether the second scale now coincides with the vertical line previously drawn with the first scale. If it does not, a factory adjustment is required.

The procedure described above should be undertaken periodically, particularly if the machine has been subject to any rough handling that might disturb its adjustment. Each scale should be used only in that groove in the scale carrier to which it has been adjusted.

In using the drafting machine, a horizontal line on the drawing should be selected as a check line, against which the horizontal scale may be checked occasionally to ensure against slippage of the paper or the machine. The scales are used for drawing horizontal and vertical lines in the same fashion as the T square and the triangles are used. After locating the scale in position to draw a line, it should be pressed firmly against the paper to prevent it from deflecting. Angles are drawn by releasing the angular indexing lever, rotating the drafting head until the desired angle is set on the angular adjustment scale, and the angular friction lock is tightened snugly. The angle is drawn with the scale which has been rotated to the proper angle. This is particularly useful in drawing views and sections taken at oblique angles. The view or section may be projected directly or may be drawn anywhere on the drawing without rotation. If it is desired to draw a set of dimensions at an oblique angle, both dimension and extension lines may be quickly and simply drawn by rotating the head to the desired angle.

A drafting machine is a precision-built instrument the usefulness of which may be impaired by rough handling. Neither the friction locks nor the tension bands should be tightened too far. The latter should produce a low-pitch tone when plucked. The drafting head should not be lifted from the drafting table if avoidable, and, if unavoidable, it should be lifted only a small fraction of an inch to prevent wracking the tension bands.

2. Templates.—Templates made of thin transparent sheets, for drawing often repeated shapes, will save a great deal of drafting time. A template pierced with holes of varying diameters may be used to draw fillet radii, holes, rivets, sheet-metal bends, bend reliefs, etc. Section letters may be drawn much faster and neater by means of a lettering template. A template with holes shaped like nut plate, nut, and bolt contours, in both plan and elevation views, will save a great deal of drafting time. The draftsman may make templates of object shapes which he uses frequently in his drafting work.

B. GRAPHICAL DEVELOPMENT OF CURVES

Smooth curves are very important in the external surfaces of an aircraft in order to obtain a smooth flow of air, thus decreasing wind resistance and increasing speed. Practically all such curves, except on airfoils used in wing and tail surfaces, may be developed as conics. A conic is defined as the curve formed by the intersection of a plane and a cone. A circle is the conic formed by a plane parallel to the base of the cone. An ellipse is a conic formed by a plane not parallel to the base of the cone but passing

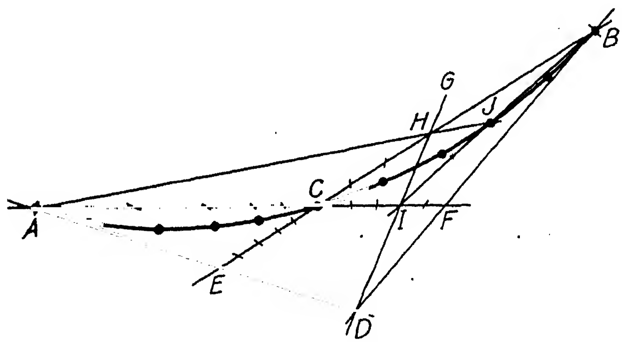


FIG. *C*.—Graphical development of a conic curve.

through every straight line drawn from the vertex of the cone on its surface (such lines are called rays). Other planes intersecting a cone differently form conics called "parabolas" or "hyperbolas." Every conic has a definite mathematical formula and can be reproduced exactly from this formula.

The solution of the formula for a conic curve is usually more difficult than a graphical solution which can be developed if three points on the curve are located and the slopes of the two end points are known (see Fig. *C*). Points A, B, and C are located, and the slopes of the curve at points A and B are given by the lines AD and BD. In developing a conic curve that will pass through these points and have the required slopes, the points and slopes are first laid out. Construction lines are drawn from A

through C to F, and from B through C to E. The points on the curve are determined by a number of lines drawn from the intersection of the tangent lines at D, intersecting lines AF and BE, only one of which, DG, is illustrated for clarity's sake. Line DG intersects line BE at H and line AF at I. Lines AH and BI are drawn and extended as necessary until they intersect at J, which is one of the required points on the curve. Other lines are drawn from D, and the construction is repeated, each time obtaining a new point until sufficient points have been obtained to draw a smooth curve through the points with an irregular curve. After drawing the curve, all construction lines are erased.

To prevent the drawing from becoming unduly confused with construction lines, only lines AD, BD, BE, and AF are drawn, and those lightly. Line DG is only drawn where it intersects BE and AF. Lines AJ and BI are only drawn adjacent to their intersection point, which may be approximately located by inspection. Only one curve can be drawn from the set of points and tangents. Two curves laid out from the same arrangement of points and tangents will coincide just as accurately as the construction has been performed. The use of conic section curves permits the exact duplication of such curves at widely separated places with only the simple basic information of the location of three points and the slopes of two tangents.

C. GLOSSARY

aileron.—A movable part of the wing, usually located in the outer rear portion of each wing. Its motion up or down changes the lift of the wing, causing the wing to rise or fall. The ailerons on the opposite sides of the airplane are moved in opposite directions, causing the airplane to rotate about its lengthwise axis.

airfoil.—A streamlined shape used in determining the contours of the wing and the tail surfaces of airplanes; various shapes have differing characteristics of lift and wind resistance.

Alclad.—A trade name for sheet-aluminum alloy covered on both surfaces with a thin layer of pure aluminum to prevent corrosion.

alloy.—A combination of metals and sometimes nonmetallic substances to produce a substance with special properties of strength, toughness, hardness, corrosion resistance, etc., not present in the original metals. The combination usually is performed with the metals in a liquid state so that they are uniformly mixed.

angle.—The amount of opening between two intersecting lines.

angle, acute.—An angle less than 90 deg.

angle, bulb.—A structural angle, the leg (or legs) having a bulb, or swelling running along its length to provide greater strength.

angle, heel of an.—The intersection of the legs at the base of the angle.

angle, right.—A 90-deg. angle.

angle, toe of an.—The outer edge of the legs of the angle.

arc.—A section of the circumference of a circle.

arc.—An electric spark.

backing plate.—A supporting plate placed behind a punch or ram of a press.

bead.—A raised or thickened section of an object, long and narrow in shape, to provide stiffness in the object.

bell crank.—A system of two or more lever arms rigidly attached to each other and pivoted so that a push or a pull in one direction may be translated to similar motion in another direction.

bend radius.—The inside radius of the bend in forming sheet metal.

bend relief radius.—The radius of the cutout in corners of formed sheet metal to eliminate fracture of the metal in bending.

billet.—A piece of material that has been shaped very roughly, usually by hammering or rolling, as the first step toward producing a finished object.

bisect.—To divide into two equal parts.

blanking.—A process of cutting or shearing parts by means of dies on a punch press.

blueprint.—An exact copy of the original drawing produced on sensitized paper.

boring.—A process of producing a very accurate hole in an object.

boss.—A protruding pad, usually circular in shape.

bracket.—A supporting member.

brake.—A machine used to produce straight bends in sheet-metal parts.

bushing.—A piece of material inserted in an object because the bushing's special properties, such as hardness, friction resistance, etc., are superior to those of the material of which the object itself is composed.

canted.—Pertaining to a sloped plane or line.

cap screw.—A screw, usually having a square or hexagonal head.

Carborundum.—A trade name for an abrasive compound used in making grinding wheels.

chord.—A straight line connecting any two points on the circumference of a circle.

clevis bolt.—A fitting with a slotted head, having a hole perpendicular to the slot.

coincide.—To have identical shape, with particular reference to two objects being identical when laid one on top of the other.

compass.—An instrument used in drawing circles.

complement.—A term applied to an angle that equals the difference between 90 deg. and a given angle.

concentric.—Two or more circles or arcs which have the same center.

cone.—A geometric figure generated by straight lines passing through a point and the circumference of a circle.

conics.—Figures formed by the intersections of planes and cones.

core.—An insert used to produce cavities in castings.

core box.—A box for holding cores in place while pouring hot metal in a casting.

counterbore.—To bore a larger size hole on the same center as a previously drilled or bored hole.

counterdrill.—To drill a larger size hole on the same center as a previously drilled or bored hole.

countersink.—To produce a funnel-shaped enlargement of the edge of a hole.

cutting plane.—A plane used in defining or locating sectional views.

degree.—A unit of angular measurement; $\frac{1}{360}$ of a circle; abbreviated "deg." or "°."

density.—The weight of a given material per unit volume.

die.—A tool used to stamp, cut, or form material to a definite shape.

dihedral.—The upsweep or angle between the wing of an airplane and the ground.

dividers.—An instrument for spacing off equal distances progressively.

draft.—The slope in the sides of a cast, forged, or pressed object, permitting the material to flow smoothly during its shaping and allowing its easy withdrawal from the forming dies.

drag.—The retarding force of air flowing over an airplane or a portion thereof.

drag.—A part of the box containing the sand mold used in the sand casting process.

edge distance.—The distance from the edge of an object to the centers of rivets or bolts.

electrode.—A member that makes an electrical contact.

elevator.—The movable horizontal surface of an airplane, usually located in the tail of the fuselage, by which the pilot changes the attitude of the airplane, *i.e.*, nose up or nose down.

ellipse.—A flattened out circle, or an oval.

empennage.—The tail section of the airplane fuselage, including elevators, rudders, stabilizers, and the portion of the fuselage to which they are attached.

erasing shield.—A thin shield (usually metal) having various shaped holes and slots, used to protect the surrounding area on a drawing while erasing a particular portion.

extrusion.—A long piece of material of constant cross section, produced by squeezing the material when in a semisoft condition through an opening of the finished cross-sectional shape.

fair.—A smoothly curved line or surface. To make two lines or surfaces join each other by a smooth curve.

fairlead.—A rubbing strip through which cables or long push rods are routed to restrain vibration, sag, or bending of the cables or push rods.

fillet.—A piece of material or structure that fills up the sharp corner of two intersecting surfaces, usually in the form of an arc.

firewall.—A fireproof structure interposed between an airplane engine or other combustion device and the remainder of the airplane to reduce fire hazard.

flutes.—The parallel grooves of a cutting tool.

flux.—An agent used in welding, brazing, and soldering to cause the joining metals to fuse more readily.

fly cutter.—A tool similar to a milling cutter but with the cutting teeth radiating from the center of the tool.

forging.—An object produced by repeated hammering of hot metal to the desired shape.

fuselage.—The body of an airplane.

fusing.—Melting.

gusset.—A flat sheet used to join two or more structural members of an airplane.

heel line.—The intersection of the planes or surfaces of an object.

hexagon.—A closed geometric figure composed of six straight sides.

hydraulic.—Pertaining to a mechanism or system operated by fluid under pressure.

hypotenuse.—The longest side of a right triangle. That side of a right triangle which is not at right angles to either of the other sides.

leader (line).—A fine line used on a drawing to lead from a dimension line to the dimension, or from a surface, area, or an object to a note.

lift.—The lifting force imposed upon an airfoil by the flow of air past it.

loft board.—A metal sheet on which lofted lines are accurately established.

lofted line.—A complex curved line established by accurate layout on a metal sheet.

longeron.—A structural member running lengthwise of the fuselage of an airplane.

lug.—A projecting part of an object, usually for the attachment of another object.

masonite.—An artificial wood product of great strength, made by pressing wood fibers together with a suitable binding agent.

milling.—The process of removing metal with a cutter rotating along the surface of an object.

minute.—A unit of angular measurement; $\frac{1}{60}$ deg. or $\frac{1}{21600}$ of a circle.

normal.—Perpendicular or at right angles.

nut, castellated.—A threaded nut, one surface of which is crossed by three slots through which a cotter pin may be inserted to retain the nut.

nut plate.—A threaded plate which may be attached to a structure so that a screw or bolt may be installed without having to hold the nut plate.

nut, self-locking.—A nut with a washer or other device to prevent the bolt or screw from vibrating loose.

oblique.—At an angle other than 90 deg., usually referring to the direction of a line or plane.

obtuse.—Pertaining to an angle greater than 90 deg.

octagon.—A closed geometric figure composed of eight straight sides.

offset.—A dimension taken from a reference line, usually two sets of dimensions at right angles to each other.

orthographic projection.—The method of delineating and projecting views, used in mechanical drawing. The lengths of all lines in a view are proportional to the lengths of the lines in the physical object.

pantograph.—A duplicating machine in which a stylus, in following an irregularly shaped flat pattern, causes a pencil, cutting tool, or other instrument to follow the same pattern on another object.

parallel.—Lines or planes that will not meet no matter how far extended.

parallelogram.—A closed, four-sided geometric figure the opposite sides of which are parallel.

part.—A part of an airplane in aircraft terminology.

parting plane.—The plane along which the two halves of the forging die separate.

pattern.—An object used to reproduce other objects of similar size and shape, usually by the casting process. Casting patterns are most often made of wood.

pentagon.—A closed geometric figure consisting of five straight sides.

perspective.—A type of drawing that gives the impression of depth on a flat sheet.

piercing.—The process of cutting out sheet metal or other material by means of a punch.

pitch.—The distance between the peaks of the threads of a screw or a nut; usually, the distance the nut will advance on the screw in one revolution.

plane.—A flat surface.

planimeter, polar.—An instrument for measuring the area of a plane figure.

polygon.—A closed figure consisting of three or more straight sides.

press, hydro.—A hydraulically actuated press for forming and shearing material.

press, punch.—A mechanically operated press that forms or shears material by a sudden stroke.

pressing.—Forming an object by compression between dies while the material is hot and plastic.

prism.—A geometrical solid the sides of which are formed by planes that intersect in parallel lines and the end planes of which are parallel.

projection.—The process of establishing an orthographic view of an object.

protractor.—An instrument for measuring the number of degrees in an angle.

pyramid.—A geometrical solid the sides of which are planes all meeting at a point.

ram.—A shaft which imparts motion to a forming mechanism, usually actuated hydraulically or mechanically.

ratio.—The mathematical relation between two quantities, usually expressed by one quantity divided by the other.

reaming.—The process of enlarging a hole to a very closely held diameter.

reciprocal.—One divided by the given number. The reciprocal of 6 is $\frac{1}{6}$.

rectangle.—A four-sided polygon, all angles of which are right angles.

rectangular.—Having the shape or properties of a rectangle, *i.e.*, at right angles.

rectilinear.—Pertaining to straight lines at right angles to each other.

rivet.—A device for holding two or more objects together by means of a shaft with swellings on both ends. The shaft fits snugly into corresponding holes through the objects and the swellings outside the hole hold the objects together. One swelling is formed before the objects are joined and the other after joining, the latter swelling being produced by hammering or pressure.

routing.—A process for removing metal to a given shape, making use of a rapidly rotating cutter and a pattern or template.

rudder.—The movable vertical tail surface of an airplane by which the pilot controls the airplane's rotation about a vertical axis.

sandblasting.—The process of removing soft material by directing at an object a blast of sand and air at high velocity.

second.—A unit of angular measurement; $\frac{1}{60}$ min. or $\frac{1}{3600}$ deg.

sector.—A part of a circle formed by two radii and an arc; a closed geometric figure shaped like a piece of pie.

serration.—A sawtooth-like ridge running along the length of a shaft or a hole. Matching series of such ridges spaced uniformly around the circumference of a male and a female object are used to prevent their rotation with respect to each other.

shear, circular.—A machine used to cut sheet metal along curved lines.

shear, straight.—A machine used to cut sheet metal along straight lines.

splines.—A series of slots of equal width and spacing, running along the length of a shaft or a hole. When male and female splined objects are joined, they rotate together but are free to move with respect to each other along their axes.

spotface.—To produce a circular flat area, usually concentric with a hole and perpendicular to it.

stabilizer.—A vertical or horizontal surface fixed to the tail of an airplane's fuselage. The flow of air past the surface tends to stabilize the longitudinal axis of the airplane in the direction in which the airplane is moving.

stiffener.—A member used to stiffen a structure, usually an angle or other thick section against a flat sheet.

stretching machine.—A machine used to form sheet metal to a complex curvature by stretching the metal over a form of the required complex curvature.

stud.—A shaft which protrudes from an object.

supplementary.—A term applied to an angle that equals the difference between 180 deg. and a given angle.

swaging.—The process of attaching a fitting to a cable or shaft by compressing the fitting around the cable or shaft.

symmetrical.—Having the same shape at equal distance on both sides of a center line.

T square.—A drafting instrument for drawing parallel lines in conjunction with a drawing board.

tail cone.—The rearmost part of an airplane's fuselage, tapering the fuselage off to a point. It is usually not a true cone, since it is not composed of straight lines and often is not circular in cross section.

tangent.—A straight line having the same direction as a point on the circumference of a circle or arc. The line touches but does not pass through the circumference.

tap.—A tool used to cut threads in a hole. To cut threads in a hole.

template.—A pattern used to lay out, cut, or draw a fixed flat shape.

threads.—Equally spaced spiral grooves or peaks in a hole or on a shaft.

tolerance.—The variation permitted on a dimension.

torque.—A twist.

torque tube.—A tube used to transmit a twisting force or motion.

trapezium.—A closed, four-sided geometric figure composed of two straight, parallel lines and two straight, nonparallel lines.

triangle, drafting.—A thin sheet of transparent material having three straight sides, two of which are at right angles to each other, used to draw perpendicular, parallel, and oblique lines.

triangle, equilateral.—A triangle with all sides equal in length.

triangle, geometric.—A closed geometric figure consisting of three straight lines.

triangle, isosceles.—A triangle having two sides of equal length and two equal included angles.

triangle, right.—A triangle one angle of which equals 90 deg.

vernier.—A device or system for measuring fractions of the division of a scale by comparing the divisions of two scales having slightly different spacings. The fraction of the division of the main scale is determined by noting which division of the vernier scale coincides with a division of the main scale.

vertex.—The intersection of two or more lines, as in an angle, a triangle, or a cone. The point of an object or a figure.

washer, lock.—A special type of washer used to prevent rotation between a tightened nut and bolt.

web.—A thin flat sheet or flat area of an object or structure used to carry the loads in the object or structure.

welding.—The process of joining two metallic objects by fusing them together.

INDEX